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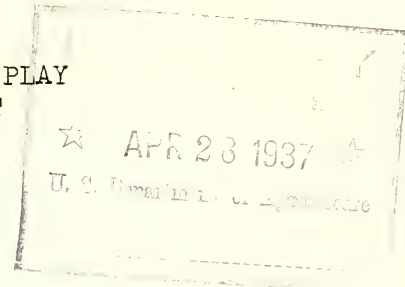
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THE PART THAT THE WEATHER BUREAU SHOULD PLAY
IN THE SOLUTION OF FLOOD AND DROUGHT
PROBLEMS

By

W. R. Gregg.



Not a year passes but has its floods and droughts. Fortunately, however, most of these are comparatively local in extent, tragic enough to the communities involved, but having no national significance. During the past decade, on the other hand, there has occurred a series of disastrous floods and devastating droughts, both of wide extent, that have imposed a severe strain on the economic resources of the country. Long-term programs, involving huge sums of money, to prevent or control floods and to mitigate the effects of droughts have been adopted and are being developed. Weather is responsible for both floods and droughts. What part should the Weather Bureau play in these programs?

Naturally its most important contribution is the issuance of timely forecasts of their occurrence. The problem is quite completely different in the two cases. Let us first consider floods.

Until recently flood forecasts were largely based on established relationships between gage readings at points up-stream and the resulting high water stage at the place in question, allowance being made of course for intervening rains. This method is very efficient for the lower sections of large basins, where floods take days or even weeks for their full development. It is wholly unsuited, however, to the source-water regions of river basins where floods develop quickly and are of the "flashy" type. Here the most important factor is the rainfall and particularly its intensity and time of occurrence. With present facilities it is possible to receive reports of the total fall during a 12-hour period, for example, but this information is not sufficient. What is needed is the hourly distribution and amount, and this can be secured only through the installation of a network of recording rain gages. Only very few are now in existence. They would have been of incalculable value in forecasting stages during recent floods, particularly those in March, 1936.

Associated with this urgent need is that of making comprehensive snow surveys in mountainous regions, in order to determine the amount of water that will be released by rains and thaws.

With the increased data thus made available and with the assignment of hydrologic specialists to devise formulae, which would include other factors such as the basin's topography, geology and vegetal mantle, the Weather Bureau would be able to assume its proper share in issuing forecasts for all rivers that would enable the proper authorities to take steps to prevent loss of human life and to reduce property losses, the latter being conservatively estimated at about two billion dollars during the past thirty-five years.

Droughts present an entirely different type of problem. Floods develop quickly as a rule. It is true that the accumulation of snow covers a fairly long period in some cases, but even so the release of the water in it is brought about, through rain and thaw, within a few days. Droughts, on the other hand, develop slowly and cover weeks, sometimes several months. Moreover, with warnings a day or two in advance, it is possible to save much property from loss by flood, but in a drought growing crops cannot be moved. Finally, floods can be controlled and prevented, in some measure at least, whereas no means are yet known for doing either in the case of droughts. The only thing possible, so far as can be seen at present, is to reduce the disastrous effects of droughts, and programs for accomplishing this are now being formulated and put into operation by various agencies.

Droughts are thus seen to be long-term affairs. The huge economic losses brought about by them could be largely eliminated, if their occurrence and extent were known in advance. This puts up squarely to the Weather Bureau the obligation to determine whether or not forecasts can be issued at the beginning of a season that will indicate, with a reasonable degree of assurance, the regions in which rainfall will be abundant or deficient and temperatures above or below normal. It is a clear challenge to the Bureau and it is accepted as such. What is being done about it?

At the outset it may be stated that this subject has received probably more intensive study than has any other one phase of meteorological research. This has been true throughout the history of the science. The recent devastating droughts have, however, given added impetus to the efforts along this line, since it is universally recognized that dependable seasonal forecasts would yield economic benefits quite beyond our power to evaluate.

Recognizing the obligation that rests upon it, the Weather Bureau is now prosecuting several lines of research designed to develop sound bases for extending its forecasts to cover longer periods than at present are attempted. In this effort the Bureau is receiving vigorous support from the Secretary of Agriculture who has approved an allocation of funds from the Bankhead-Jones Act for fundamental research. One of the projects to which these funds are being devoted is a comprehensive survey, review and appraisal of everything that has been published in the past relative to the various lines of attack on the problem of long-range weather forecasting. It is expected that a report of this survey will be available within the next few months. It is hoped that the work under this project will enable us to reach rather definite conclusions concerning the practicability or validity of the various approaches to the problem.

In the meantime several investigations, previously begun, are being continued, such as (1) the possible relationships between conditions in one part of the world and subsequent conditions in other regions; (2) the existence of cycles or periodicities and their use in seasonal pre-

diction; (3) the influence of variations in ocean temperatures on the weather in adjacent countries; (4) variations in solar radiation, and their effects upon the earth's weather; and several others, which have been proposed from time to time as offering a hope for issuing longer period forecasts than are justified at present.

Naturally, the solution of this problem would be of great aid also in predicting excessive precipitation and therefore floods, and in this one respect floods and droughts have something decidedly in common. There would be many other applications of long-range forecasts; in fact, they would quite completely change our economic and social structure.

Briefly summarizing, we know that, with only a modest increase in funds, the flood forecasting work of the Weather Bureau could be vastly improved and, in fact, put on a high plane of efficiency. As to droughts, the problem is to develop dependable bases for long-range weather forecasts. Frankly, the results thus far are not particularly encouraging, but that fact provides all the greater incentive to attack the problem with determination to solve it if possible. This we are doing and, in the effort, are receiving the cooperation of many agencies and individuals both in and out of the Government service.

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RECENT TRENDS AND THE FUTURE IN METEOROLOGICAL SERVICE.

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☆ APR 24 1937 ☆

(Address by Willis Ray Gregg, Chief, Weather Bureau, before the Iowa Chapter of the Society of the Sigma Xi, Iowa City, Iowa, April 21, 1937)

The history of science shows clearly that progress is not always, not even usually, a process of steady development, but rather that it has been characterized by a series of accelerations or sudden spurts intermingled with periods of quiescence, sometimes of retrogression. Meteorology presents an excellent example of this cyclic tendency. For a brief period, under the guiding hand and brain of Aristotle, it flashed out in brilliance, then slumbered for twenty centuries. Now, the renaissance which began a hundred years ago or so bids fair to eclipse many fold any former achievement and to bring meteorology into a position of dignity and usefulness quite on a par with that held by other utilitarian sciences. This is eminently proper, for we are convinced that none other can contribute more to human efficiency, to human welfare and to human happiness than can meteorology, and most of them not as much.

Before taking up recent and present trends and the future, it will, perhaps, be worth our while to review briefly the history of meteorology and the development of weather service. Undoubtedly weather is the most talked about topic that the human race possesses. It has been so since the dawn of history, probably for countless ages before. The cave man no doubt scanned the sky carefully each morning, grunted his satisfaction or muttered some primordial oath, and formulated his plans for the day on what his observations revealed. He and his more enlightened successors gradually evolved certain, fairly definite relationships between signs of the sky and other things that they saw and the weather that actually followed. Thus, comparatively early in his history, man became a fore-caster as well as an observer. Many of the weather proverbs that he expressed in quaint rhymes have more than a kernel of truth in them and are useful even to the present day.

Broadly speaking, this represents the extent of progress in weather service up to something like a century ago. Owing to the development, about that period, of the telegraph, the discovery of certain fundamental physical laws and the introduction of instrumental apparatus, particularly the barometer and the thermometer, a very active and world-wide interest was aroused in the possibility of adapting weather service to human activities. Almost simultaneously many countries organized fairly extensive networks of observational stations and endeavored to use the data in predicting what the weather would be a day or two ahead.

From that time on, down to the early part of the present century, considerable progress was made in developing new and improved types of instrumental apparatus, in extending the range of observations and in applying the data to the problems of forecasting. Gradually observational stations were established over the entire country and even beyond, including Alaska and the West Indies. Simultaneously Canada, Mexico and many

other countries organized similar services and the first steps were taken in effecting an international exchange of reports. Tremendous progress was made in this field with the introduction and use of radio, for this made it possible to receive data from ships at sea, one of the most important developments in the entire history of weather service. Through international conferences arrangements were made for the adoption of uniform methods of making, recording and publishing observations. Moreover, codes for international exchange and symbols for entering the data on weather maps have, so far as possible, been standardized. All of this has resulted in making the data, generally speaking, directly comparable, thus facilitating the study of weather and climate on a world-wide scale.

Meanwhile, increasing attention has been given to the exploration of the upper air, concerning which up to the beginning of the present century practically nothing was known. Kites and manned balloons had their day. They were succeeded by small free balloons, some of them carrying instruments, and most recently by airplanes which go up quickly to 3 or 4 miles and bring down a complete record of temperature and humidity at all heights reached.

The study of these records in the vertical, together with those in the horizontal, has brought out many useful relationships, our knowledge of the physical processes of the atmosphere has immeasurably increased and, as a result, important advances have been made in the precision and accuracy of forecasts. Notwithstanding all this, we must admit that the surface has, after all, barely been scratched. Much remains to be done to bring weather service to the state of excellence of which it is capable. We believe that such improvement is perfectly possible. We are confident, moreover, that we are on the threshold of this important development, that we are, in fact, entering a new epoch. What is the basis of this optimism? In other words, what are the present trends in weather service? There are several of them. Let us briefly examine two. They are:

First, a more detailed and intensive type of service than has heretofore existed.

Second, the development of a forecasting technique based on sound physical laws, utilizing for this purpose the greater abundance of observational material only recently available.

First, then, let us consider the tendency to organize weather service in a more detailed and intensive way than formerly. Aviation is more largely responsible for this than any other activity, but a beginning had previously been made in connection with the protection of citrus and other fruits from frost. About a quarter of a century ago it was found that the ordinary generalized type of forecast did not meet the needs of fruit growers. Accordingly, first in California and later in other sections of the country, a special service was set up which provided for frequent observations from a close network of stations in and near the fruit districts, and short period, specific forecasts issued in the evening for the following morning. This enabled orchardists to take protective measures by lighting fires in the groves, thus keeping the temperatures above the danger point. Millions of dollars worth of damage have been prevented by this service.

Undoubtedly, however, the greatest impetus to the organization of this special type of service was given by aviation. For this activity it is vital that weather conditions be reported with great accuracy not only along the airways but also for a considerable distance on either side in order that the development of unfavorable weather may be predicted before it reaches the flying routes. Moreover, the general daily forecasts were found quite inadequate. It was necessary to develop a new type, very definite and covering a period of about the same length as that of the flight itself. Accordingly, for the most active airways there are now hourly reports from a dense network of stations and six-hourly forecasts, special attention being given to such unfavorable conditions as fog, low clouds, poor visibility, squalls and ice formation. There is room for much improvement, but, within the limits of the funds that have been provided, as rapid progress as possible has been made, and you will be interested to learn that an increase in the appropriation will enable us to strengthen this service still further after July 1 next.

These two examples show, somewhat dramatically, the benefits that result from an intensive type of weather service. The question naturally arises: If good for them, why not for other activities also? The answer is that we are tending in that direction right now. Let me cite a few examples.

It is scarcely necessary for me to tell you of the Central West that a most direct relationship exists between weather conditions and agriculture. You undoubtedly know that, during the crop growing season, weather reports are received from a large number of sub-stations, supplementing the more complete data from our larger primary stations. The data thus secured, when summarized and studied, make possible an estimate of the probable yield of wheat, corn and other crops, this estimate becoming more definite, of course, as the season advances, but being very helpful also even in the early months of the summer half of the year. Extensive as this service is, we realize that it can be greatly strengthened by having a considerable number of additional observing stations, particularly for rainfall which is very local in character and differs widely within short distances. This then is one of the objectives toward which we are directing attention. Not much can be done along this line right now, but we are hopeful that additional funds will later enable us to put this highly important service in a status to which it is entitled.

While on this subject of weather and agriculture it may be of interest to interrupt our main theme and discuss briefly some recent occurrences which are of special concern to you and which have focussed attention on an age-old question, "Is Our Climate Changing?" I refer to the devastating droughts that have afflicted this country during the past seven years.

Droughts may be considered under two general heads, first, the transitory type; second, the cyclic, widespread type.

Practically all regions of the world where vegetation flourishes are subject to droughts of the first type. As a rule they cover comparatively small areas, for only part of a season, and are largely fortuitous or accidental in character. As is well known, much of our precipitation in

the summer half of the year comes from thunderstorms which are local in character. On the average the distribution of these is fairly general when we think in terms of a month or more, but occasionally it may happen that a region is, so to speak, completely passed by for a comparatively long period.

Of much more importance from the viewpoint of economic consequences is the cyclic, widespread type of drought such as we have been having during the past few years. Meteorological and other records show that more or less periodically these widespread periods of excessively dry weather occur not only for one year but several times within the space of something like ten years. One of the most severe of these is the series that began in 1930 and reached its most serious stage thus far during 1936, with another disastrous intermediate minimum of precipitation in 1934.

I said that this series of droughts is of the cyclic type. In other words, it is by no means unprecedented but had its almost exact counterpart between forty and fifty years ago, namely, from 1886 to 1895. It is interesting to recall that conditions in the so-called "Dust Bowl" were quite as severe in 1894 and 1895 as during the past three years. Not as much publicity was given to them, partly because fewer people lived there, partly because the economic results of crop failures were not as great then as now, and partly because facilities for publicity were not then developed in any such measure as at the present time.

Meteorological records were, of course, much less complete a hundred years ago than now, but those available, as well as references in newspapers and in the literature of the time, indicate that there was a very severe series of droughts between 1830 and 1840.

Then, too, we have the very conclusive evidence from studies of tree rings that there was a long, dry period between 1755 and 1780.

Between these dry periods there was in all cases an abundance of precipitation, more than ample in many of the years for crop growing purposes, and there is every reason to believe the same will be true after the present minimum phase of the cycle has passed. Periods that were notably wet were 1865-'85 and 1900-'20.

The question is often asked "What causes droughts?" The answer is not that there is an absence of moisture in the atmosphere. On the contrary, almost invariably there is an abundance of it, but the trouble is that during these periods the ordinary processes of nature are altered in such a way that the moisture remains in the air instead of condensing and falling as rain. As is well known, air that contains moisture must be cooled in order that the water vapor may be condensed in the form of clouds and ultimately fall as rain. For the most part this cooling is accomplished through rising of the air, which is brought about in several ways but most effectively through the meeting of great masses of differently constituted air, one, warm and moist from the tropical regions, and the other cool and dry from the polar regions. The latter being heavier forces the warm, moist air to rise. This results in cooling, which in turn brings about condensation and precipitation of the water vapor.

Normally, in temperate latitudes there is an almost endless succession of meetings of these differently constituted air masses, so that rains come generally at intervals of a few days. During certain periods, however, there is a breaking down or interruption of this process. The atmosphere seems to become stagnant over wide regions and for long periods of time, and we have the phenomenon of droughts that we have been experiencing during the past few years.

This is the explanation of droughts, but you will note that it does not go back to fundamentals. Why at certain more or less regular intervals of time this interruption to the normal process occurs is not now known. It is a subject on which we are concentrating our efforts. Its solution would result in economic benefits in connection with agricultural planning that would be incalculable. We do not know that the occurrence of widespread droughts is anything other than accidental, but the fact that they come at more or less regular intervals of time certainly suggests that there is probably some underlying physical basis, possibly solar, perhaps terrestrial, or a combination of the two, and as I stated before we are giving earnest study to this problem at the present time.

Droughts invariably raise two other questions; one, "Can man do anything to prevent or overcome them?" and two, "Is the climate changing?"

The answer to the first question is definitely negative. Many proposals have been put forward that have a sound physical basis and that work admirably in the laboratory, but are economically impossible in Nature's laboratory, the atmosphere. For example, building fires on an enormous scale, dusting the sky, electrically charging the free air, cooling the air, and many others would bring some results, but their financing would wreck the Nation in a few days.

Recently we have been repeatedly urged to load all the airplanes in the country with water from the Great Lakes and sprinkle the drought devastated areas. This proposal is undoubtedly made in good faith by everyone who has suggested it, but the correspondence always ends abruptly when we inform the writers that to give a rainfall of only one inch for one acre of ground would require 113 tons of water. This is a good illustration of the enormous scale on which Nature works and of the utter futility of man's attempting to compete, except in a very local way and then only through the use of what Nature has already placed at his disposal; for example, through irrigation.

Returning now to our main topic, time permits us only to mention some other examples of the present trend toward greater detail and specialization in weather service. One such is the river and flood service, for which we are planning additional gaging and rainfall stations at strategic points in all river basins where floods, unless accurately forecast, cause immense damage and danger to life; again, the fire-weather service which has recently been considerably enlarged and which warns in advance of weather conditions, such as low humidity, thunderstorms and high winds, that are favorable for the inception and spread of destructive forest fires. Another example is the recently organized hurricane warning service which provides for hourly reports from stations along the Gulf coast, frequent

reports from ships in the Gulf, the West Indies and the Caribbean, and forecast centers at New Orleans and Jacksonville. Finally, there is the marine weather service which should be, and we hope soon can be, materially strengthened by providing for regular reports from all ships four times each day instead of twice as at present. Experience has conclusively shown, not only the high importance of these more detailed reports as current information, of benefit to both marine and aerial navigation, but also their great value in indicating the development of storms which shortly approach and travel across land areas and thus affect the lives and activities of all of us.

Now, the question arises, what are we doing with all this increasing wealth of material? That brings us to the second of our recent trends in weather service, namely, developing forecasting as a science based on sound physical laws. Doubtless all of you have heard something about air mass analysis. In brief, it means simply a study of the physical structure of the various masses of air which, originating from different regions and having different characteristics of temperature, moisture and wind, eventually meet somewhere and, because of their widely different structure, engage in a conflict, so to speak, to determine which is master, the result frequently being a turbulent and unstable condition, gusty and squally winds, rain, snow, thunderstorms; in other words, practically everything that we denote as "bad weather". The theory of all this has been known for a long time, but weather services have never been able to apply it in a practical way, to any large extent, because of the lack of necessary data. Now we are getting the data, in increasing measure, as I have already told you. We are using the information in making detailed physical analyses of each day's weather map, including particularly the conditions in the upper air, as measured and reported for us by balloons and airplanes.

With the subject of forecasting is always associated the question as to the possibility of extending the period to include several days, weeks, months, possibly a year or more. Among scientists there is a wide diversity of view as to whether or not such forecasts will ever be possible, but their economic and social benefits would be so vast that we should be recreant to our duty, as a Government agency, did we not bend every effort to the solution of this problem. Accordingly, we are investigating the subject with renewed energy and with a determination to run down every reasonable, that is to say, every scientific approach. We are confident that some extension of the daily forecast to 2, 3 or even 4 days ahead will be possible and that the more general weekly outlook will be somewhat lengthened. Further than this I can only express the hope that our present studies, and others to be taken up later, will yield a basis, possibly, for general statements as to the weather a month, a season or even longer ahead, but I must emphasize that this at present is only a hope.

We come now to the part of our discussion which we should approach with considerable caution, namely, the question "What of the Future?" We must bear in mind that the history of science furnishes abundant proof of the fact that it is extremely rash to predict future scientific developments. The advances in one branch of science frequently depend upon advances in others, and, in many cases, those of a practical character are a response to new social needs and conditions that cannot be foreseen. How-

ever, if anyone may be considered to have the right to delve into the future, it would seem that the meteorologist should have that right, since meteorology, more than any other science, with the possible exception of astronomy, attempts to do that very thing. The following remarks are therefore hazarded with a full realization of the difficulties involved.

Already we have emphasized two significant developments of the past few years which will almost certainly lead to progressive improvement in the general character of weather service. One of these is an increase in basic observational material and the second is its analysis and application in accordance with sound physical laws. It can be said without fear of contradiction that our greatest difficulty at present is in securing the necessary data for such analysis. We believe that this difficulty is destined to be eliminated, to a substantial degree, through the use of radio, and that a definite beginning will be made in the near future.

During recent years, particularly the last two or three, marked progress has been made, both in the United States and in various European countries, in the development of what is known as the radiometeorograph. This is an instrument consisting of a radio transmitter which is actuated by an aneroid barometer, a bi-metallic thermometer, and a hair hygrometer, all of extremely light weight but of high precision. The apparatus is suspended from a small rubber balloon filled with hydrogen, which ascends at the rate of about 600 to 800 feet per minute and reaches heights sometimes as great as fifteen miles or more. During the ascent signals are sent to a recording station, where they are converted into actual values of pressure, temperature, and humidity on the basis of calibrations previously made.

Some further development needs to be made but the progress already accomplished indicates clearly that this method of upper air exploration will shortly be brought to a point where it can be used as a substitute for all other methods heretofore employed. Its general adoption and use will really mark the beginning of a new epoch in meteorological service, because observations will be possible under all types of weather conditions and at much greater heights than are at present attainable. Other methods, like the kite and the airplane, have the weakness that they cannot be used during very bad weather conditions, and also are limited to the lower half of the troposphere. A very important feature of the radiometeorograph is that it will enable us to secure reports from the stratosphere as well as all of the troposphere. Another great advantage is that the data will be immediately available, since they will be communicated to the earth by radio while the balloon is ascending.

When these instruments are perfected, it is planned to establish a large number of stations, probably forty to fifty, well distributed throughout the country, and to have observations made certainly once every day, possibly oftener. The data will be assembled at central points and there charted and analyzed. As I have previously stated, this use has during the past two years been made of similar data secured by airplanes and some improvement in weather forecasting has already resulted. With the much more complete and regular information from radiometeorograph records, it is certain that the work now being conducted in air mass analysis will

become increasingly effective and that further improvement in forecasting will be realized. In addition, the data will be of great value in indicating the current conditions along the airways throughout the country, and thus be of use in the practical business of flying.

There are many applications to which the principle involved in the radiometeorograph can be put in addition to those concerned with the problems of the upper air. For example, a series of these instruments placed on small islands, many of them uninhabited, in the West Indies and Caribbean Sea will provide data of inestimable value during the hurricane season. The same use can be made of the apparatus on islands in the regions which are subject to destruction by typhoons.

It is generally recognized that great benefit will result from more detailed information regarding conditions in the polar regions. Such information will be secured through the organization of a network of stations in regions where man does not live. It will be perfectly feasible to install the equipment which will transmit the data as frequently as desired, and which can be kept functioning through only very rare inspection visits by means of an airplane.

Again, much thought is being given at present by practically all meteorological services to the desirability of taking up mountain observatory work more actively than ever before. The great difficulty is that establishing observatories on very high summits involves many problems and large cost. The radiometeorograph will solve this problem also, and at comparatively small expense.

The possibilities for the use of the principle of the radiometeorograph or the "robot observer" are, in fact, almost endless and abundantly justify all the feverish activity that is now in evidence in many countries in bringing equipment to a point where it can be used in regular service.

With this large increase in our observational material we can look forward, we believe, to steady progress in its application to the problems of forecasting and to the extent that this progress is realized life on the earth will become increasingly attractive and worth while. Death and suffering and property loss will be greatly reduced. Transportation by air, land and sea will become safe, so far as weather is concerned. Our natural resources will be conserved, crop failures largely prevented, our daily health greatly improved, our span of life lengthened. In short, the world will be a far better place in which to dwell than it now is or ever has been.

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W 37 Add

WEATHER FORECASTING, WITH SPECIAL REFERENCE TO HYDROLOGY AND AERONAUTICS

(Address by Willis Ray Gregg, Chief, U. S. Weather Bureau, before The
Hartford Engineers Club, Hartford, Conn., December 16, 1937)

RECEIVED

Introduction ★ JAN 3 1938 ★

U. S. Department of Agriculture

The issuance of weather forecasts is and probably always will remain one of the most important functions of a meteorological service. There are many others, equally valuable, but forecasting affects the lives of all the people and hence is the activity by which we are most widely known and most frequently and at times most critically judged. This being true, it behooves us to put forth every possible effort to make the forecasts progressively more and more accurate. A correct answer, every day, to the question "What's the weather going to be?" would completely revolutionize the economic and social life of our Planet. Even a close approach to that ideal would bring about profound changes. Can we ever hope to realize this objective? Before attempting to answer this question it will be worth our while to review briefly the history of forecasting up to the present time.

Development of Forecasting through the Ages

Before the dawn of history no doubt the Cave Man went blunderingly forth day after day without so much as a glance at the sky. Gradually, however, he and his somewhat less primitive successors noted that certain signs, such as colors of the sunrise and sunset, circles around the sun or moon, etc., were followed more frequently by a particular type of weather than by any other. This was the first forward step in weather service.

Down through the centuries since then the number of these relationships between "signs of the sky" and weather the next day or two has greatly increased, and many of them have been put into quaint rhymes, known to us as "weather proverbs." Some are quite dependable, others less so, but nearly all have more than a kernel of truth in them. Many a wise sailor has avoided disaster by heeding these forecasts provided by Nature herself.

Something like a century ago man suddenly awoke to the fact that nationally organized and operated weather services would be of great use to him in planning his day's work. This urge on his part, together with the development of the telegraph, the discovery of fundamental physical laws and the construction of instrumental equipment, particularly the barometer and the thermometer, brought about the organization of weather services almost simultaneously by nearly all civilized countries of the world. Since then there has been gradual but consistent progress. Through radio the observational field has been extended to the sea and to isolated regions on land. Experience of the past and studies now

under way are teaching us much about the physical structure of the atmosphere. Thus, although by no means perfect, weather service does now form an essential aid in the economic and social life of all peoples.

Present Status of Forecasting

Ever since national meteorological services began to be organized, about 1870, forecasts have been based in large part on the familiar synoptic weather map, which shows the geographic distribution of the meteorological elements and their changes from day to day. It is well known that weather conditions travel in a fairly regular manner, altering more or less as they move, and it is possible, from a detailed study of past synoptic charts, to estimate from a current map the changes that will take place during the next day or two in the location of cyclones or "Lows" (regions of relatively low pressure) and anti-cyclones or "Highs" (regions of relatively high pressure) and in the accompanying weather conditions that are characteristic of these pressure formations. Much progress was made during the early years of use of this method, but, being empirical, a "dead line" of dependability was presently reached beyond which further improvement is not attainable.

During this early pioneer period many theoretical investigations clearly established the fact that it is not the cyclones and anticyclones as such that are important in determining weather, but rather the interactions between the various air masses that go to make up those systems of high and low barometric pressure. These air masses from different source regions, polar, equatorial, continental and marine, have distinct characteristics of temperature, humidity and movement, and they tend to maintain their individual identities over comparatively long periods of time, with the result that at their surfaces of contact they form more or less marked discontinuities or "fronts." It is along these frontal surfaces that the processes involved in weather phenomena are most active, and the study of them, now generally referred to as "air mass analysis", already has proved itself a powerful aid in developing forecasting along sound physical lines and is destined, we believe, in the not very distant future, to result in substantial improvement in the accuracy and precision of the forecasts and probably also in a moderate extension of the period covered by them.

The effective application of air mass analysis to the problems of forecasting was until recently not possible, owing to the lack of sufficiently detailed data at the surface and more particularly in the upper air. These deficiencies have in part, and in part only as yet, been overcome. Radio has greatly assisted by making reports available from sea and from distant continental sections. Codes have been adopted which yield greater detail in the data transmitted. Most significant of all perhaps is the introduction of the airplane in making upper air observations. Airplanes have their limitations as to height and regularity, but they are now providing at about twenty-five places in this country invaluable data up to about 5 kilometers, quite promptly and in all weather conditions except those that are too hazardous for flight. There is thus made available for analysis information regarding the vertical structure of the atmosphere, including its pressure, temperature

covered by the forecasts ranges from 2 or 3 days in the upper valleys to as much as 3 or 4 weeks in the lower Mississippi Basin.

As a rule, it is impracticable to use gage relation or discharge data in making flood forecasts for regions into which flow numerous small streams, which may be considered source-water streams. These numerous headwater or source-water streams, and the channels that are water carriers only during heavy rains, cannot be gaged in a way that would make the observations valuable in flood forecasting. The channels are too numerous and gaging them is not economically practicable, even though it might be possible in some cases. Therefore, it becomes necessary to rely upon reports from rain gage stations placed in the catchment basins in a way that will give the forecaster a clear and current knowledge of the amount and intensity of the rain, and its geographic distribution. In much of the country east of the Appalachian Mountains flood forecasts to be timely enough to be of real benefit must be made from rainfall reports.

This last statement was strikingly illustrated in the floods of March 1936. Practically all of the rivers involved were comparatively small ones and the time between the fall of the heavy rains and the occurrence of flood stages was very short. It was impossible to make forecasts on the basis of stages in the upper parts of these small rivers.

The floods of January 1937 illustrate the application of both approaches to the problem of flood forecasting. The forecasts for the Mississippi, for example, were almost entirely on the basis of the upstream stages. Those in the Ohio on the other hand were in considerable part based on the occurrence of the heavy rain that prevailed for the greater part of the month on ground that was already saturated.

The prelude to the record-breaking floods in the Ohio Valley during January 1937 was a gradual building up of conditions favorable to producing maximum floods. There was abundant precipitation, ranging from near normal to considerably above normal, rather generally east of the Great Plains. Thus, at the beginning of January, the ground was in a well saturated condition allowing a high percentage of run-off from any further rain that might fall. Also, the Ohio River and its tributaries began a slow rise at the close of December due to the above normal precipitation during December. The Wabash River was in flood and the Tennessee and Cumberland Rivers had sharp rises at the beginning of January.

Practically the entire month of January was characterized by a high pressure area located in the vicinity of Bermuda and another just west of the upper Mississippi River with a trough of low pressure midway between these two areas. The trough of low pressure extended in a southwest to northeast direction from eastern Texas to western Pennsylvania and varied very little from this position during the entire month.

This pressure distribution brought about a strong influx of warm, moist air from the Gulf of Mexico over the Ohio Basin. This warm, moisture-laden air over-ran a mass of cold air and was in contact with it from western Pennsylvania to eastern Texas. This resulted in heavy

downpours of rain along the Ohio Basin and upper Mississippi River from Pittsburgh, Pa., to Memphis, Tenn.

The persistence of the high pressure area over Bermuda prevented the eastward movement of the masses of air so that practically all of the excessive rainfall was confined to the Ohio Valley and lower Mississippi River. Some precipitation fell on the 1st and 2nd but the heavy rains began on the 7th. By the 10th the lower Ohio River began exceeding the flood stage at Evansville, Ind., and Cairo, Ill., and on the 19th the river was flooding over its entire length from Pittsburgh, Pa., to Cairo, Ill. The all time record of 71.1 feet at Cincinnati, Ohio, which occurred on February 14, 1884, was broken in the early morning of the 23rd. The river then rose steadily beyond this point until on the morning of the 26th the water had risen to the almost unbelievable height of 80 feet, which is 28 feet above the flood stage. All previous records were broken along the Ohio River from slightly below Parkersburg, W. Va., to the mouth, and the record discharge from that stream produced the highest stages of record in the Mississippi River from Cairo, Ill., to the mouth of the Arkansas River and also at Natchez, Miss.

In these floods snow was not a serious factor, but very often it is. This is particularly the case if a considerable depth of snow has accumulated and a spell of very warm weather, accompanied by rain, occurs. Even then the floods ordinarily do not become serious unless the rainfall is fairly heavy. In other words, what is needed is the accurate and timely forecasting of rainfall, particularly in regions where rivers are small and of fairly steep slope, and therefore where the floods are what are called of the "flashy" type. Headwater forecasting has now the attention of the Bureau's hydrologists and rapid gains are being made in applying the more recently developed conception of rainfall-runoff relationships to streamflow estimation.

Future Plans in Hydrologic Service

We have already discussed the more urgent needs, and they have also been given much attention by other agencies, in cooperation with the Weather Bureau, including the National Resources Committee, the Soil Conservation Service, the American Society of Civil Engineers and the Army Engineers. In order to meet these needs it has been necessary to reorganize this branch of the Bureau's service in such a way as to bring about a much closer coordination with agencies in charge of flood control programs and more attention to fundamental research. The more important features of the reorganization, which is being put into effect as rapidly as funds permit, are as follows:

One of the most pressing needs is to provide the forecaster with means of estimating tributary streamflow, both quantitatively and from rainfall. Accordingly, the country has been divided into 9 hydrologic regions, 5 of which recently have been provided with regional offices and personnel. The regional offices are being manned by qualified hydrologic engineers who will gather hydrologic data, develop methods of estimating streamflow, devise means of assembling flows and coordinate and unify the forecasting program within the respective regions.

The necessity to organize promptly for an expanded service in important headwater areas has been recognized by the Commonwealth of Pennsylvania. A project, engaged in cooperatively by the State, the Geological Survey, and the Weather Bureau has as its objective the development of modern forecasting methods for the streams of the State. Among the first steps in the plan has been the establishment of what is almost a completely new hydrologic data-base. It is now generally understood that the newer hydrologic methods of estimating streamflow from rainfall cannot utilize published rainfall and streamflow records as 24 hour averages. Accordingly, 130 recording rainfall stations and about 15 additional streamflow stations have been established on the watersheds of the Allegheny, Monongahela, Susquehanna, and Delaware Rivers.

It is interesting to note that, including the 500 recording rainfall stations recently established on the Muskingum watershed, there is now a continuous net of closely spaced recording rain gages covering the greatest area so served in this country. This net, if extended west to include the Scioto and Miami Conservancy Districts, would provide a record of short duration rainfall north of the Ohio River from the Delaware River to Indiana.

Engineers will be interested in knowing also of the hydrologic studies recently inaugurated cooperatively with the Corps of Engineers for the purpose of estimating spillway and waterway capacities. These studies are to be sufficiently broad in scope to include much that will be of general value to engineers. The procedure of transposing storms for the purpose of estimating limiting flood flows is gaining in favor among those who bear the responsibility for the design of spillways and waterways. The hydrologic studies referred to will undertake to determine regional storm potentialities for the country as a whole and to develop a technique of storm transposition.

The unusual interest manifested in hydrology in recent years has created a difficult situation for the Weather Bureau. In past years there was only an occasional call for the continuous records of rainfall kept at our first-order stations throughout the country. However, such recent developments as the unit-hydrograph, the idea of transposing storms, and an accelerated activity in general hydrologic research have created a demand for a more complete hydrologic data source than now exists. A long range plan, the first step of which we hope can be taken within the next year or two, provides for the establishment of nearly 3,000 additional recording rainfall stations over the country.

Our river service, in its expansion in the West, is making effective gains in the development of improved methods of measuring snowfall. Hydrologic research has recently begun in Yellowstone Park where, on three selected watersheds, basic relationships between snowfall, snow-melt, temperature, ground surface conditions, and run-off are to be studied.

These are some of the main features in our reorganization plans. Although they relate mostly to the future, some of them already are in operation to some extent and the experience with them thus far assures us that, when fully worked out, they will result in very decided im-

provements in the service that the Weather Bureau provides to engineers and to others who are engaged in the solution of hydrologic problems.

Meteorology and Aeronautics

The history of the application of meteorology to aeronautics is an interesting one, but time does not permit us to go into the subject here. I have already referred to the airplane itself as an agency for securing information regarding upper air conditions. It has come into regular use only recently. It had several forerunners. So early as 1872, in the "Report of the Chief Signal Officer" we read: "The experiment of a balloon ascension has been tried with fair results. The ascension was made by contract had with a professional aeronaut, and had in view the determination of the question whether the proper instruments could be carried and used with needful accuracy, an observer-sergeant being charged with the duty. One hundred and fifty-six readings were made during the ascension. The experiment is thought to have established that very delicate instruments may be employed hereafter, if it is considered advisable."

This prophecy was to be abundantly fulfilled in later years. The manned balloon itself, however, owing to its cost and other undesirable features was soon displaced by other devices, including particularly large, so-called box kites and small balloons of various types such as the captive, pilot and sounding balloons. With kites soundings were made to an average height of somewhat less than 2 miles, occasionally up to 3 or 4. They provided data on pressure, temperature, humidity, wind and heights of clouds. Their use was limited, however, to days with moderate winds. Captive balloons took the place of kites during calm or very light wind conditions. Pilot balloons, introduced about 20 years ago and still extensively used, give us wind data up to great heights, but only below cloud layers. Of great importance, especially in studies of the stratosphere, are sounding balloons which rise to heights of 15 or 20 miles. They carry instruments which make a continuous record of pressure, temperature and humidity, and, during clear weather, when theodolite observations are possible, they provide wind data also. After the balloons burst, the instruments are let down slowly by means of parachutes. They may land almost anywhere, usually a considerable distance from the starting point, and thus the data are not available for current use.

As previously stated, the airplane has recently come into quite general use, taking the place of kites and captive balloons. On the average it reaches heights of about 3 1/2 miles, but, because of the hazard involved, fails at times during bad weather which is just the time when we need the information most.

All of these methods thus are seen to have serious limitations. Nevertheless they have provided data of incalculable value, both in a statistical sense and as current information. Particularly was this true during the World War when the proper design of aircraft demanded a knowledge of the characteristics of the upper air at different heights, particularly as regards its density, but including also pressure,

temperature, and humidity. Later, in connection with the determination of regular flight schedules, came a similar need for data regarding wind conditions at various heights along air routes. It was a happy circumstance that the thousands of soundings that had been made largely because of their theoretical interest during the quarter of a century prior to about 20 years ago served also, in a very direct way, the practical needs of aeronautics. The operation of the Air Mail by the Post Office Department from 1918 to 1926 clearly demonstrated, however, that the weather service then existing was much too generalized. For this activity it was found necessary, in fact vital, that weather reports be available at more frequent intervals and from a larger number of places, both along and off the airways. Certain weather elements not previously measured were essential, such as visibility and ceiling, or height of the lowest cloud layers. Moreover, the general daily forecasts were quite inadequate to meet this new demand. They must be much more detailed and specific and cover a shorter period corresponding approximately to that of the flight itself, namely, 3 to 5 or 6 hours.

At the same time it was found that certain other aids, such as intermediate landing fields, beacon lights and prompt communication facilities were required both for safety and for efficiency. A growing recognition of these needs culminated in the adoption on May 20, 1926, of what is known as The Air Commerce Act which authorized the Department of Commerce to provide all necessary navigational and other aids except weather service, this last duty being naturally assigned to the Weather Bureau.

Present Status of Airway Weather Service

During the ten years since the passage of this Act weather service for aeronautics has undergone a profound evolutionary development, being today specialized to a degree that would have been regarded as wholly fantastic and unwarranted a quarter of a century ago. And, interestingly enough, this same tendency is now finding expression in changes in the character of service for other activities, as has been indicated already in the case of one of them, namely, hydrology. It would be tedious to outline this development in detail, but a brief account of the service as it is now functioning will, it is believed, be of interest.

There are at present some 33,000 miles of civil airways, including those in Alaska and the Hawaiian Islands, and about half of these on which flying is more or less continuous are provided by the Department of Commerce with 24-hour teletype service. Along these 16,000 miles of airways hourly weather reports are regularly transmitted from stations so located as to provide a complete picture of current conditions and of changes from hour to hour. Intermediate observations also are made when marked changes occur. On airways which are as yet less active and therefore are not provided with teletype service, observations ordinarily are made less frequently, but nevertheless at such intervals as to insure covering adequately all regular scheduled flights.

In addition to these reports from points on the airways others are received every six hours from well located off-airway stations.

Two of these collections include data from the Bureau's primary or basic system of reports from all first-order stations, from Canada, Alaska, Mexico, the West Indies and from the oceans.

Of great importance are the measurements of upper air conditions by means of pilot balloons and airplanes, the use of which has already been referred to. Additional information regarding conditions aloft is obtained from observations of clouds, particularly the heights of their bases as determined with small so-called ceiling balloons in the day time and with ceiling lights at night. Then too there are the reports from mountain stations and from pilots flying along the airways.

All in all, the airway service embraces nearly 800 stations of various types, some providing reports only of surface conditions, others including upper air data also and still others adding to these functions that of maintaining direct contact with pilots and officials of the air transport companies themselves. Of this last type there are now more than 50 stations at the larger terminal and many intermediate airports, where weather maps are made and pilots and others kept advised of conditions in all parts of the country in which they are interested, this service being on a 24-hour basis throughout the year. Eleven of these airport stations are district forecast centers, where personnel of proved technical ability in forecasting also provide continuous service, issuing four times daily forecasts for the next 8 hours, with supplementary warnings in cases in which conditions are rapidly changing and differ from the prediction previously made. These forecasts not only are given to those interested locally, but are widely distributed, along with the reports of current conditions, by the Department of Commerce communication system which includes, in addition to teletype, an extensive network of radio stations, thus enabling pilots in flight to be kept constantly informed of current conditions along all parts of their routes and of predicted changes. The forecasts are expressed in very definite terms, with special emphasis being given to ceiling, visibility, line squalls, ice formation and any other conditions that present a real hazard. They indicate also the upper wind conditions, thus enabling pilots to select an altitude where the flight can be made with the greatest possible speed consistent with safety.

The Future in Airway Service

Such in brief are the main features of the airway meteorological service as it functions at the present time. Only an extreme optimist would claim that it is ideal. It is only about 10 years old. During this period there has been much experimentation, with changes and improvements resulting as suggested by experience. There is reason to believe that the basic and essential features are sound and will probably endure, but there are bound to be further improvements as new ideas and methods are proposed and introduced. The Weather Bureau is now actively engaging in many research projects, all designed to bring about such improvements. Time permits us to consider only one of these, but a most promising one, namely, the development of what is known as the radiometeorograph or radiosonde.

We have already stressed the vital importance of securing an uninterrupted series of upper air soundings to great heights and we have also pointed out that all methods at present in use are subject to serious limitations with the result that we often fail to secure data when most needed. We believe that the radiometeorograph offers the solution. Briefly, this is an instrument consisting of a radio transmitter which is actuated by an aneroid barometer, a bi-metallic thermometer, and a hair hygrometer, all of extremely light weight but of high precision. The apparatus is suspended from a small rubber balloon filled with hydrogen, which ascends at the rate of about 600 to 800 feet per minute and reaches heights sometimes as great as fifteen miles or more. During the ascent signals are sent to a recording station, where they are converted into actual values of pressure, temperature, and humidity on the basis of calibrations previously made.

Some further development needs to be made but the progress already accomplished indicates clearly that this method of upper air exploration will shortly be brought to a point where it can be used as a substitute for all other methods heretofore employed. Already it is in use experimentally at 3 stations in this country and at Fairbanks, Alaska. Its general adoption and use will really mark the beginning of a new epoch in meteorological service, because observations will be possible under all types of weather conditions and at much greater heights than are at present attainable. A very important feature of the radiometeorograph is that it will enable us to secure reports from the stratosphere as well as all of the troposphere. Another great advantage is that the data will be immediately available, since they will be communicated to the earth by radio while the balloon is ascending.

When these instruments are perfected, it is planned to establish a large number of stations, probably sixty to seventy-five, well distributed throughout the country, and to have observations made certainly once every day, possibly oftener. The data will be assembled at central points and there charted and analyzed. As I have previously stated, this use has during the past two years been made of similar data secured by airplanes and some improvement in weather forecasting has already resulted. With the much more complete and regular information from radiometeorograph records, it is certain that the work now being conducted in air mass analysis will become increasingly effective and that further improvement in forecasting will be realized. In addition, the data will be of great value in indicating the current conditions along the airways throughout the country, and thus be of use in the practical business of flying.

There are many applications to which the principle involved in the radiometeorograph can be put in addition to those concerned with the problems of the upper air. For example, a series of these instruments placed on small islands, many of them uninhabited, in the West Indies and Caribbean Sea will provide data of inestimable value during the hurricane season. The same use can be made of the apparatus on islands in the regions which are subject to destruction by typhoons.

It is generally recognized that great benefit will result from more detailed information regarding conditions in the polar regions. Such in-

formation will be secured through the organization of a network of stations in regions where man does not live. It will be perfectly feasible to install the equipment which will transmit the data as frequently as desired, and which can be kept functioning through only very rare inspection visits by means of an airplane.

Again, much thought is being given at present by practically all meteorological services to the desirability of taking up mountain observatory work more actively than ever before. The great difficulty is that establishing observatories on very high summits involves many problems and large cost. The radiometeorograph will solve this problem also, and at comparatively small expense.

The possibilities for the use of the principle of the radiometeorograph or the "robot observer" are, in fact, almost endless and abundantly justify all the feverish activity that is now in evidence in many countries in bringing the equipment to a point where it can be used in regular service.

With this large increase in our observational material we can look forward, we believe, to steady progress in its application to the problems of forecasting and, to the extent that this progress is realized, life on the earth will become increasingly attractive and worth while. Death and suffering and property loss will be greatly reduced. Transportation by air, land and sea will become safe, so far as weather is concerned. Our natural resources will be conserved, crop failures largely prevented, our daily health greatly improved, our span of life lengthened. In short, the world will be a far better place in which to dwell than it now is or ever has been.

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DR. JOHN LINING - PIONEER AMERICAN METEOROLOGIST.

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(Remarks by Willis Ray Gregg, Chief, U. S. Weather Bureau, on the occasion of the unveiling of a tablet to Dr. John Lining, Charleston, S. C., January 11, 1938) ★

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U. S. Department of Agriculture

The pioneer plays a role at once the most fascinating and the most valuable of any that the human race can pursue - fascinating because nothing appeals quite so much as finding something new, as being, in effect, an explorer and discoverer; and valuable, for the pioneer opens up new vistas which yield to mankind greater efficiency, greater comfort and greater happiness than previously enjoyed. Webster gives this definition: "Pioneer - one who goes before, as into the wilderness, preparing the way for others to follow; as, pioneers of civilization, of reform, or in science; also, an early settler, a colonist; as, the American pioneers."

Dr. John Lining met several of these specifications in the highest degree, but it is his work in meteorology and its applications that places his name securely among those who stand out as American pioneers in science. This is not to say that he was the first, or even among the first, to make notes of the weather and its ways. Twenty centuries before his time Aristotle, with the powerful backing of Alexander the Great, organized a network of approximately one thousand stations from which the observers sent him data concerning many natural phenomena, including the weather. And the first text book on meteorology, or the science of the weather, was written by Aristotle, a book by the way that was accepted as final authority on the subject for two thousand years and which gave correct explanations of many phenomena, such, for example, as the formation of rain.

Down through the ages are found many other records of the weather, fragmentary for the most part, but nevertheless of great interest and in some cases of considerable value. But, all of these early observations were made without instruments. Even in the colonies we have a few scattering records before Dr. Lining began his work, but these again gave no quantitative values and therefore, though interesting, have no real statistical significance.

The great contribution that Dr. Lining made is the notable series of observations with instruments, the first in this country, begun in 1738 and continued past 1750. The late Professor Alfred J. Henry of the Weather Bureau writes as follows regarding these data:

"This series possesses in a remarkable degree many of the refinements of later years. Dr. Lining was an eminent physician and an investigator of a high order of merit. Coming to Charleston about 1730, he entered upon the practice of medicine and continued an active practitioner upward of thirty years. The climatic conditions of Charleston were radically different from those of his native country, Scotland, and it is, therefore, not surprising that he should have been led to observe the weather with that degree of care and skill so characteristic of his professional work."

Dr. Lining was chiefly interested in determining relationships between weather conditions and the occurrence of epidemics, especially of yellow fever. Along with his daily observations he conducted an elaborate series of statistical experiments upon himself. He wrote to the Royal Society regarding these as follows:

"What first induced me to enter upon this course was that I might experimentally discover the influence of our different seasons upon the human body by which I might arrive at some certain knowledge of the cause of our epidemic diseases which regularly return at their stated seasons as a good clock strikes 12 when the sun is on the meridian."

Thus, we see that Dr. Lining was not so much interested in his observations as statistical data, valuable though they be, as in their possible relation to epidemic diseases, undoubtedly with the thought that this knowledge might lead to remedial measures that would lessen the severity of these outbreaks. Another example of the breadth of Dr. Lining's scientific interest was his performance of experiments to draw electricity from the clouds by means of a kite during 1753, following the example set by Benjamin Franklin a year earlier.

Aside from the practical purposes that were served by Dr. Lining's records, they constituted the first contribution to a study of the climatic characteristics of the country. In all of the States and territories, as the frontiers were pushed farther and farther westward, other men and women with the pioneering spirit, secured instrumental equipment and proceeded to keep records. Later there developed organized efforts along this line, by the Smithsonian Institution, by the War and Navy Departments, by many of the States and then, in 1891, by the U. S. Weather Bureau. The work so splendidly begun by Dr. Lining is now carried on in thousands of places throughout the world, there being more than 5,000 in this country and its possessions alone. With the exception of a limited number of first order stations such as the one here in Charleston, nearly all of these observations are made by what are known as "cooperative observers" who are supplied by the Government with the necessary equipment, but who render their service without any pay whatsoever, entering every day, on blank forms provided them, the values of temperature, rainfall and other conditions and forwarding the report each month to the State Climatological Center.

In South Carolina there are nearly 60 such stations. It is worthy of note that at 5 of them the observers have rendered this daily service, without pay, for more than 25 years:

W. O. Jeter, Santuck, 44 years
M. M. Calhoun, Greenwood, 41 years
H. K. Gilbert, Florence, 33 years
James C. Faris, Catawba, 30 years
L. M. Parker, Calhoun Falls, 26 years.

Why do they do it? Why are busy men and women willing to obligate themselves to devote a quarter of an hour at the same time every day in

performing a service without compensation? For the most part we think they are impelled by the same motives that prompted Dr. Lining to conduct his laborious experiments and calculations, - a love of the truth, a desire to know more about nature's laws, an urge to do something useful for others. There are 5,000 such men and women in the United States. All honor to Dr. John Lining who set the example for them to follow.

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PROGRESS IN WEATHER FORECASTING

(Address by Willis Ray Gregg, Chief, U. S. Weather Bureau,
at meeting of the American Institute of Electrical Engineers,
Washington, D. C., June 22, 1938.)

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INTRODUCTION



I have been asked by the Chairman of your Program Committee to give a general view of progress in weather forecasting, with chief emphasis on the forecasting of major storms and disasters, such as floods, hurricanes, etc., all of which affect in a vital way the electrical services, both power and communication, with which the work of most of your membership is quite directly concerned. Before taking up this general subject, however, it is proper, and it is also a privilege and a pleasure, to point out that, without the aid and achievements of the electrical engineer, meteorological service as we know it would be utterly impossible. We should still be dependent on the astrologer, on the goosebone, rheumatic joints, Saints' Days, the ground hog, almanacs of various kinds, et cetera ad nauseam. It is interesting to recall that organized meteorological observations were not unknown to antiquity; in fact, Aristotle received reports from several hundred stations and wrote the first known treatise on the subject, but the reports were received by messenger; therefore, too late for current use.

Telegraph, Telephone and Teletype.

Down through the centuries other attempts were made to do something about the weather, not merely to talk about it, but it was only when electric communication was provided that anything really worth

while could be done about it. And it is significant that, within five years of the date, 1844, when the telegraph first came into public use, it was employed by the Smithsonian Institution in collecting weather reports for the purpose of forecasting storms. Its utility and value in this connection were quickly sensed by other countries. In November, 1854, a violent storm wrought havoc among the French and British war-ships in the Black Sea and sank many vessels containing invaluable stores intended for the allied armies in the Crimea. The French astronomer, Le Verrier, director of the Observatory of Paris, collected information showing the progress of this storm across Europe, and the results of this inquiry were so significant that he submitted to the Emperor Napoleon III the plan of organizing an international system of telegraphic reports, by means of which timely warning could be obtained of similar atmospheric disturbances. The French Government, with the aid of other European countries, established such a system in 1855. Within the next two decades most of these countries organized their own services, and at the same time maintained an international exchange of observations by telegraph. Our own service was officially authorized in 1870. Thus we see that within a generation of the time when the telegraph became available as a means of communication, practically all civilized nations were making use of it in providing daily forecasts and warnings for their peoples.

Later came the telephone which supplemented the telegraph in a most effective way, both in the collection of reports and particularly in the dissemination of meteorological information, including forecasts and warnings, to millions of people requiring such service. When you consider that more than 8,000 telephone calls were received and answered

at the Weather Bureau office of one large city, in the short space of 24 hours, during a flood emergency, you can realize the tremendous importance of this means of communication in performing the functions of a meteorological service.

Then there is the teletype which provides an almost instantaneous exchange of reports at frequent intervals along more than 21,000 miles of airways and, during the hurricane season connects a large number of reporting stations along the Gulf of Mexico and South Atlantic coasts. It is destined to be still further extended, eventually combining into one system the entire network of meteorological stations in this country and probably in others.

Radio

And finally the radio. It is not too much to say that its introduction and widespread use marked the beginning of an epoch comparable only to that initiated by the telegraph. It has extended our meteorological horizon to the seas and to remote and isolated regions of the continents. The first weather report from a ship in the Atlantic was received December 3, 1905; in the Pacific, June 18, 1907; and in the Caribbean, August 26, 1909. In 1906 the total number of marine reports received was 738; in 1922, 1,500; in 1933, 56,800; and in 1937, 89,165.

The record as regards land reports is no less noteworthy. International exchanges were begun in 1921, and at the present time twice daily bulletins are received from Rugby and Cavite as well as individual reports from many other points, including several stations in northern Siberia, northern Canada and Greenland. The Isles of the Pacific and of the Caribbean add their quota to this ever increasing volume of data, with the result that we now have twice-daily weather maps of the

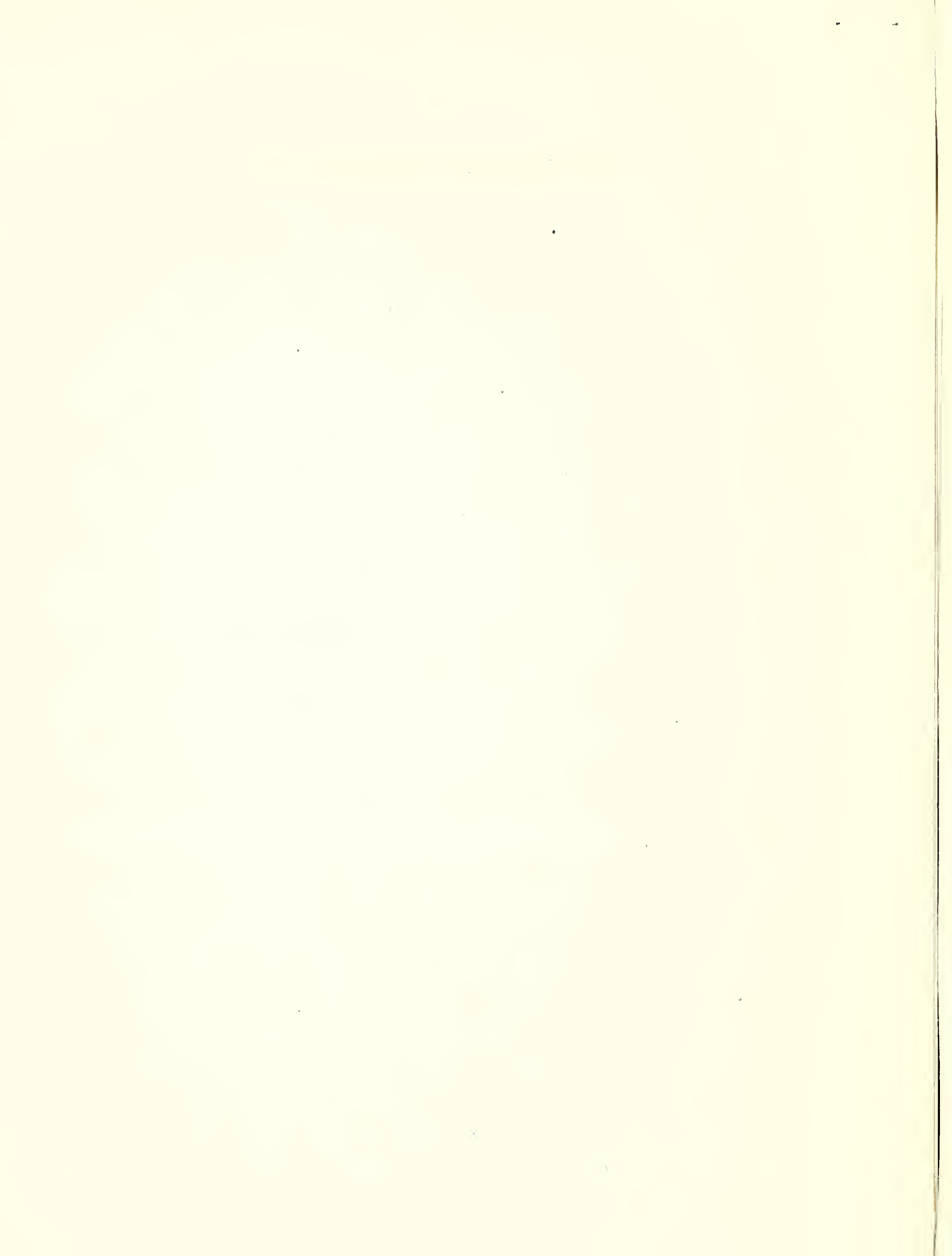
entire Northern Hemisphere and the time is not far distant when we shall have such maps for the whole world.

So much for radio as a collector of reports. Its role as a disseminator is equally impressive. Through the Naval radio broadcasts were begun in 1904. All marine interests now receive forecasts and warnings in this way. Radiophone broadcasts in this country were begun in 1921, the first one being by the University of Wisconsin on January 3, 1921. The first flood warnings were broadcast by the University of Missouri on April 26th of the same year. At present there are 435 radiophone stations regularly broadcasting forecasts and warnings for the benefit of the farmer, the merchant, the shipper, the orchardist, the housekeeper, the baseball fan, the motorist and the golfer. Radio not only guides the aircraft pilot on his way but keeps him constantly informed of current weather ahead of him and of impending changes. In short, it is difficult to visualize a meteorological service without radio as a chief factor. Yet, with all that it is and does, undoubtedly we have made only a beginning in taking advantage of its possibilities. Already complete weather maps are being transmitted to ships at sea. This service is in the experimental stage at present, but will certainly be extended and will include ships in the air and distant land stations also. But the most far reaching development, now rapidly passing out of the experimental phase, is that wherein radio plays the role of a meteorological observer as well as that of a transmitter of the data. I refer to the apparatus that is variously known as the radio-sonde, radio telemeter, or, generally up to the present time in this country, as the radiometeorograph.

Significance of the Radiometeorograph
in Meteorological Service.

Time does not permit more than a brief statement regarding the design of this instrument. It consists essentially of a radio transmitter which is actuated by a barometer, a thermometer and a hygrometer, all of extremely light weight but high precision. Four principles of operation have been employed. The most widely used is the Olland system of telemetering (a simple form of television) in which an attempt is made to telemeter the position of the index of the meteorological element relative to a time scale. The next in order of general use is one in which the meteorological elements vary the capacities of the radio frequency oscillator thereby varying the carrier frequency. Another principle of operation is to key the carrier by means of the meteorological elements, thus causing a sequence of coded signals to be transmitted. Finally, there has been employed an audio oscillator whereby the carrier frequency is modulated and produces variations in modulation by changes in resistances that are varied by the meteorological elements.

Each of these designs has certain advantages and disadvantages. It is too early as yet to say definitely which one will ultimately prove to be the most efficient, but all have been brought to a point already where they give reasonably reliable data. During the present fiscal year different designs have been used by the Weather Bureau at three places and it is our present plan to extend the program to include six stations beginning July 1st. The experience of this coming year and the improvements resulting from that experience will, it is believed, enable us to adopt one design, or possibly a combination of the best



features of two or more, as the most efficient, and to substitute this method of upper air exploration for others heretofore employed, so far as pressure, temperature and humidity are concerned. There remains the problem of adapting this apparatus to include measurements of air movement. This is difficult but it is being attacked and there is good reason to expect that it will be solved.

The regular use of the radiometeorograph will unquestionably mark the beginning of a new epoch in meteorological service. Attached to a balloon it will ascend to heights of 10 to 20 miles, therefore well up into the stratosphere. It will secure data in all conditions of weather, thus overcoming a serious handicap to which all other methods are subject. And finally it will give us those data immediately while the balloon is ascending instead of our having to wait two or three or more hours after the sounding is completed.

Nor will the benefits be limited to our knowledge of the upper air. These instruments, or apparatus based on the same principle, can be placed on small islands, - for example, in the West Indies and Caribbean Sea to give data of inestimable value during the hurricane season. The same use can be made of the apparatus on islands in regions which are subject to destruction by typhoons.

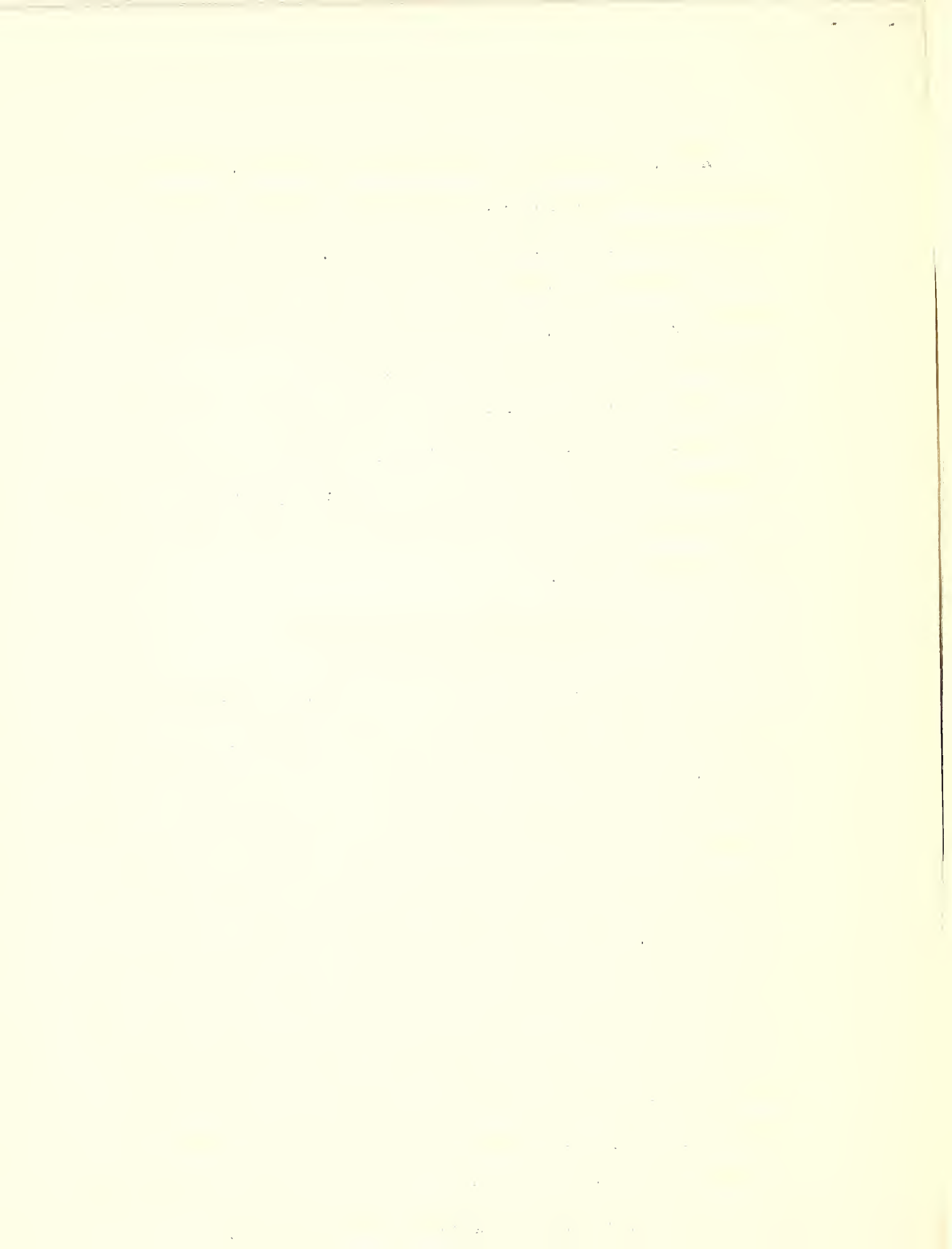
It is generally recognized that great benefit will result from more detailed information regarding conditions in the polar regions. Such information will be secured through the organization of a network of stations in regions where man does not live. It will be perfectly feasible to install the equipment which will transmit the data as frequently as desired, and which can be kept functioning through only very rare inspection visits by means of an airplane.

Again, much thought is being given at present by practically all meteorological services to the desirability of taking up mountain observatory work more actively than ever before. The great difficulty is that establishing observatories on very high summits involves many problems and large cost. The radiometeorograph will solve this problem also, and at comparatively small expense.

The possibilities for the use of the principle of the radio-meteorograph or the "robot observer" are, in fact, almost endless and abundantly justify all the feverish activity that is now in evidence in many countries in bringing the equipment to a point where it can be used in regular service.

Present Trends in the Development of Meteorological Service

I have dwelt at some length on the subject of communications, particularly radio, partly because it seems appropriate, on an occasion like this, to pay tribute to the electrical engineering profession for its contribution to meteorological service and partly because the rapid development of communication facilities makes possible a corresponding extension of the observational field, both in the horizontal and in the vertical. Hand in hand with these advances have come improvements in instrumental design, in the training of personnel and in international standardization of codes, units, symbols and definitions, with the result that data from all sources are becoming progressively more accurate and are directly comparable, in addition to being promptly transmitted. Thus, meteorological services are being provided with the working tools that are essential for the development of those services in line with two chief present-day trends which are:



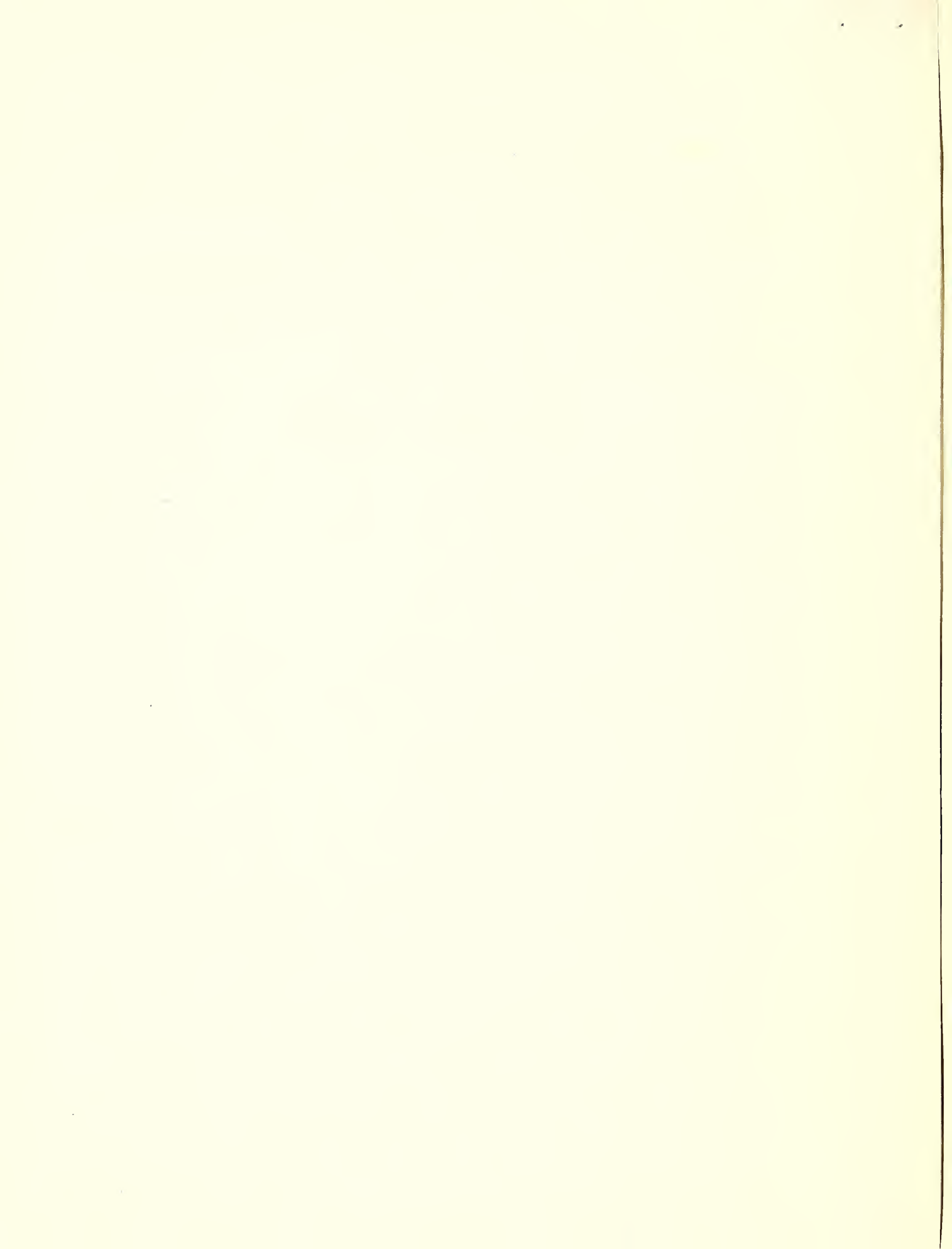
First, the application of sound physical laws to forecasting, displacing empirical methods on which until recently, owing to lack of sufficient data, dependence was necessarily placed.

Second, the organization of a more detailed and intensive type of service to meet the specific needs of individual interests and activities than has heretofore been provided.

Physical Basis of Forecasting

As has been pointed out already, attempts to use simultaneous reports from a network of stations as a basis for forecasting were made very shortly after the telegraph became available, but it was not until about 1870 that official meteorological services were organized by the various Governments. Since that time chief dependence has been placed on the well-known synoptic map, which shows the geographic distribution of the meteorological elements and their changes from day to day. It is well known that weather conditions travel in a fairly regular manner, altering more or less as they move, and it is possible, from a detailed study of past synoptic charts, to estimate from a current map the changes that will take place during the next day or two in the location of cyclones or "Lows" (regions of relatively low pressure) and anti-cyclones or "Highs" (regions of relatively high pressure) and in the accompanying weather conditions that are characteristic of these pressure formations. Much progress was made during the early years of use of this method, but, being empirical, a "dead line" of dependability was presently reached beyond which further improvement is not attainable.

During this early pioneer period many theoretical investigations clearly established the fact that it is not the cyclones and anticyclones as such that are important in determining weather, but rather the inter-



actions between the various air masses that go to make up those systems of high and low barometric pressure. These air masses from different source regions, polar, equatorial, continental and marine, have distinct characteristics of temperature, humidity and movement, and they tend to maintain their individual identities over comparatively long periods of time, with the result that at their surfaces of contact they form more or less marked discontinuities or "fronts". It is along these frontal surfaces that the processes involved in weather phenomena are most active, and the study of them, now generally referred to as "air mass analysis", already has proved itself a powerful aid in developing forecasting along sound physical lines.

The introduction of a new technique, especially when it involves the use of data of a type not previously available, requires careful study to determine the most effective means of presenting those data for rapid and thorough analysis. The "raw" observational material is useful in showing the current state of the individual meteorological elements, but offers little aid in an understanding of the energy transformations that are taking place. For this latter purpose various so-called "energy diagrams" have been devised which bring out clearly the more prominent characteristics of the air masses that are present and give us a picture of the structure of the atmosphere as regards its temperature, humidity and other conditions.

The adiabatic chart is the fundamental diagram for plotting the data from individual ascents. The sounding is plotted with temperature as abscissa, and pressure on a logarithmic or exponential scale as ordinate which is approximately equivalent to a linear altitude scale. On the diagram, we may readily locate the various temperature inversions

(atmospheric strata in which the temperature increases instead of decreases with height) which are significant as marking the tops of turbulent and convectively-stirred regions and which also coincide with the tops of haze, smoke, and cloud layers. Furthermore, these temperature inversions, especially if accompanied by inversions in the vertical distribution of moisture, may signify the presence of frontal surfaces. Adaptations of the adiabatic chart have been devised, from which the energy realizable for vertical convection can be determined, - one of the few precise physical computations that can readily be applied to forecasting and is of great value in forecasting local showers and thunderstorms. The procedure consists in following the changes that would occur were an isolated element of surface air forced to move upward along an adiabatic line, and comparing its temperature, and therefore its density, at each level with that of the surrounding atmosphere through which the element is forced to rise; the conditions in the surrounding medium are given by the data of the airplane observation. If the isolated rising air finds itself in an environment that has a lower temperature, then it will not be in stable equilibrium and will be accelerated upward, thus being capable of producing the strong ascending currents necessary for the formation of thunderstorms. In its ascent the air, after reaching the condensation level of its water vapor, cools at the so-called saturation or pseudoadiabatic rate, which is less rapid than the adiabatic cooling rate before condensation because of the gradual release of the latent heat of vaporization in the cloud. A convective-energy diagram called an "emagram", based on the adiabatic chart, with temperature as abscissa and pressure as ordinate, is highly useful, since it shows, by its so-called "positive area", the amount of



energy that is available for convection.

Another valuable form in which the upper air conditions can be quickly visualized is by means of the so-called "vertical section" which shows observed and equivalent potential temperatures, relative and specific humidities, winds, clouds, etc., as ordinates and a geographic section of the country, west to east, north to south, or any other direction, as abscissae. Necessarily the vertical scale is greatly exaggerated. Several such vertical sections are required to show the conditions for the entire country. We have not as yet been able to devise a method that would combine all into one chart, nor is it likely that we ever shall be. However, a study of these vertical sections, together with the surface weather map, enables one to form a fairly comprehensive picture of the distribution, both horizontal and vertical, of the various air masses and of the surfaces of discontinuity separating them.

One of the most recent and most promising advances in charting the upper air is the development of the so-called isentropic charts. This method is based on the fact that in the free atmosphere, most movements are along adiabatic or isentropic surfaces, i.e., surfaces of constant potential temperature; potential temperature is defined as the temperature attained in an adiabatic reduction of pressure to 1000 millibars (one million dynes per sq. cm.). Instead of drawing charts of the air currents on level surfaces, or surfaces of constant height, we chart the circulation along the isentropic surfaces, which normally are sloping surfaces, and thus we follow the currents along the surfaces on which they actually move. The paths of the air currents can be traced by following the course of "tongues" of water vapor maxima

that appear on the charts. These moist tongues, especially where they are carried in currents moving rapidly upward along the isentropic slope, are correlated with areas of precipitation and cloudiness. In forecasting the behavior of these tongues, one can arrive at a very good idea of the future course or development of precipitation areas. A study of these charts has shown that the atmospheric circulation tends to break up into much smaller eddies than was previously supposed to be the case. New theories of the general circulation of the atmosphere are being developed from these findings.

Now the question naturally arises, what are the practical results thus far achieved? In answering this question we must bear in mind that two or three years constitute a very short period, and we should not be discouraged if the results are no more than suggestive of what may be expected from further use of any new method. Happily, however, in the present case we have some results that are not merely suggestive as to the future but which show definite improvement along some lines already.

It was early recognized that air mass analysis would find its most effective application in the short period forecasts such as are required for the safe and efficient operation of activities along the airways. Within a year after the introduction of frontal analysis in the Weather Bureau the practice was adopted of transmitting over the airway teletype system information as to the location of fronts, and these have been placed on the weather maps that are prepared several times daily at all airport stations. It is well known that material improvement has resulted in the general character and accuracy of this type of forecast, as is abundantly attested not only by our own

officials, but also by the recipients and users of the forecasts themselves.

Can as much be said in the case of the longer period, that is, the regular 24 to 36 hour forecast? Not to the same extent as yet, but there are certain definite results already and they are all in the right direction. They show that our original plan to integrate the analyses and their applications to forecasting with the already existing forecast procedure and with the accumulated knowledge and experience in the past has, even in the short period thus far devoted to its development, made considerable progress in the forecast service at the Central Office in Washington. For more than a year now the intermediate weather maps that have been analyzed in detail by the trained personnel of the air-mass section have been furnished as a guide for quick and reliable analysis on the principal morning and evening maps by the forecasters. The forecasters report that "this helps materially in readily locating the fronts and identifying the different air masses on these maps. Therefore, the forecasts are always expeditious and at times are issued with more confidence because of greater assurance of a correct analysis of the current map."

With wholly inadequate funds for research, with not even enough for the barest needs of current service, for that matter, progress necessarily is slow but it is positive, to a degree that has justified an extension of the program to field stations. A beginning along this line was made several months ago, through the detail of an official in our Air Mass Analysis Section to important forecasting centers in the airway service. In the meantime several young men who have received special training at the Central Office and have returned to field assign-

ments are passing on to others some of the knowledge they have gained.

Specialization in Forecasting.

All of this leads naturally to a consideration of the second chief trend in the development of modern meteorology, namely, providing a more detailed and intensive type of service, including forecasts, to meet the ever increasing demands incident to the initiation of new activities, or the expansion of already existing activities, in our complex social and economic structure. Until comparatively recent times a generalized type of service was accepted as reasonably satisfactory or, at any rate, as the best that could be had. No one thought very much about a more detailed service. All this is now completely changed. Every activity that is more or less affected by weather; in agriculture, commerce, marine and aerial navigation, demands and, in increasing measure, is receiving a specialized and intensive type rather than the more generalized type of a few years ago. At that time and during the half century preceding it the official of a Weather Bureau station provided service for all types of activities. He was, so to speak, a "Jack of all trades" and, therefore, through no fault of his own, "master of none." Now, on the other hand, specialists are employed who have had intensive training in a particular branch of the service and devote all of their attention to it. This change is wholly in harmony with the spirit of our own time which, as we all know, is one of specialization to a greater degree than has been any previous age. In conforming to this fundamental change, practically all branches of the Bureau's service have been very materially modified and, we believe, definitely improved. A few examples may be of interest.

Airway Service

Undoubtedly the greatest impetus to the organization of specialized service was given by aviation. For this activity it was found necessary, in fact vital, that weather reports be available at more frequent intervals and from a larger number of places, both along and off the airways. Certain weather elements not previously measured were essential, such as visibility and ceiling, or height of the lowest cloud layers. Moreover, the general daily forecasts were quite inadequate to meet this new demand. They must be much more detailed and specific and cover a shorter period corresponding approximately to that of the flight itself, namely, 3 to 5 or 6 hours.

At the same time it was found that certain other aids, such as intermediate landing fields, beacon lights and prompt communication facilities were required both for safety and for efficiency. A growing recognition of these needs culminated in the adoption on May 20, 1926, of what is known as The Air Commerce Act which authorized the Department of Commerce to provide all necessary navigational and other aids except weather service, this last duty being naturally assigned to the Weather Bureau.

During the twelve years since the passage of this Act weather service for aeronautics has undergone a profound evolutionary development, being today specialized to a degree that would have been regarded as wholly fantastic and unwarranted a quarter of a century ago. There are at present some 33,000 miles of civil airways, including those in Alaska and the Hawaiian Islands, and about two-thirds of these on which flying is more or less continuous are provided by the Department of

Commerce with 24-hour teletype service. Along these 21,000 miles of airways hourly weather reports are regularly transmitted from stations so located as to provide a complete picture of current conditions and of changes from hour to hour. Intermediate observations also are made when marked changes occur. On airways which are as yet less active and therefore are not provided with teletype service, observations ordinarily are made less frequently, but nevertheless at such intervals as to insure covering adequately all regular scheduled flights.

In addition to these reports from points on the airways others are received every six hours from well located off-airway stations. Two of these collections include data from the Bureau's primary or basic system of reports from all first-order stations, from Canada, Alaska, Mexico, the West Indies and from the oceans.

Of great importance are the measurements of upper air conditions by pilot balloons and airplanes, and, more recently, as previously stated, by radiometeorographs. Additional information regarding conditions aloft is obtained from observations of clouds, particularly the heights of their bases as determined with small so-called ceiling balloons in the day time and with ceiling lights at night. Then too there are the reports from mountain stations and from pilots flying along the airways.

All in all, the airway service embraces nearly 800 stations of various types, some providing reports only of surface conditions, others including upper air data also and still others adding to these functions that of maintaining direct contact with pilots and officials of the air transport companies themselves. Of this last type there are now more than 50 stations at the larger terminal and many intermediate airports,

where weather maps are made and pilots and others kept advised of conditions in all parts of the country in which they are interested, this service being on a 24-hour basis throughout the year. Eleven of these airport stations are district forecast centers, where personnel of proved technical ability in forecasting also provide continuous service, issuing four times daily forecasts for the next 8 hours, with supplementary warnings in cases in which conditions are rapidly changing and differ from the prediction previously made. These forecasts not only are given to those interested locally, but are widely distributed, along with the reports of current conditions, by the Department of Commerce communication system which includes, in addition to teletype, an extensive network of radio stations, thus enabling pilots in flight to be kept constantly informed of current conditions along all parts of their routes and of predicted changes. The forecasts are expressed in very definite terms, with special emphasis being given to ceiling, visibility, line squalls, ice formation and any other conditions that present a real hazard. They indicate also the upper wind conditions, thus enabling pilots to select an altitude where the flight can be made with the greatest possible speed consistent with safety. As earlier stated, the techniques developed in our air mass analysis work have contributed very effectively in improving this branch of the Bureau's work.

Such in brief are the main features of the airway meteorological service as it functions at the present time. Only an extreme optimist would claim that it is ideal. It is only about 10 years old. During this period there has been much experimentation, with changes and improvements resulting as suggested by experience. There is reason to

believe that the basic and essential features are sound and will probably endure, but there are bound to be further improvements as new ideas and methods are proposed and introduced. The Weather Bureau is now actively engaging in many research projects, all designed to bring about such improvements.

Hydrologic Service

Although river and flood forecasts have been issued since 1871, it is only recently that this problem has been attacked with due regard to the engineering phase. This has come about partly because of the series of floods that have brought disaster to many parts of the country and partly because of legislation authorizing a comprehensive program of flood control.

Flood forecasting utilizes two methods which differ markedly in principle. On the larger rivers and on the lower reaches of the smaller streams gage relations are sufficiently consistent to permit an accurate estimate of expected stage far enough in advance to make adequate preparation for evacuation of areas doomed to inundation. Forecasts are developed progressively downstream, properly adjusted to increase in flow from important tributaries. The period covered by the forecasts ranges from 2 or 3 days in the upper valleys to as much as 3 or 4 weeks in the lower Mississippi Basin.

As the headwaters are approached, however, prediction of river stage becomes increasingly complicated. The amount and rate of the rainfall, the slope of the land and the stream channel, the character of the watershed and its cover, and the influence of antecedent rainfall - factors which have been integrated into terms of stage on the

lower river - now become variables which must be dealt with separately and quantitatively.

Our nation is rapidly becoming flood conscious, with the result that the Weather Bureau has been forced to extend its river forecasting service into the headwater areas of nearly all the principal streams. There has been neither time nor opportunity to prepare for basic changes which involve method and procedure wholly without precedent. At many important up-river stations, the forecaster has only a comparatively few hours to foretell the approach of a flood and that under the conditions of "flashy" stream flow typical of headwater tributaries. Pittsburgh is perhaps the best example of such a situation. Any plan to meet this problem must be prepared to predict flood stage practically as the rain falls and the snow melts. The city itself must be organized to evacuate certain areas with the precision of a fire department. Industry and business occupying danger zones must plan to waterproof against the rising water or to remove damageable goods to higher levels on minimum notice. This city, and other municipalities so situated, must maintain stand-by emergency water supplies and lighting facilities. Permanent concentration centers must be selected in advance and emergency housing provided. These and other plans in considerable detail are being formulated by the agencies charged with the responsibility of dealing with great floods.

The flood of January 1937 in the Ohio and lower Mississippi rivers illustrates the application of both approaches to the problem of flood forecasting. The forecasts for the Mississippi, for example, were almost entirely on the basis of upstream stages. Those for the Ohio on the other hand were based in considerable part on the occurrence

of the heavy rain that prevailed for the greater part of the month, causing the upper river to crest 24 to 36 hours after the rain ceased.

In order to meet these rapidly increasing needs it has been necessary to reorganize the hydrologic branch of the service so as to bring about a much closer coordination with agencies in charge of flood-control programs and to permit greater participation in fundamental research. To this end the country has been divided into twelve hydrologic regions, five of which are now provided with regional offices and personnel. The regional offices are being manned by qualified hydrologic engineers who will gather data, develop methods of estimating stream flow, devise means of assembling flows and coordinate and unify the forecasting program.

As rapidly as funds permit, the network of recording rain-gage stations is being extended. Increasing attention is being given to the accurate measurement of evaporation and special studies are being made to determine basic relationships between snowfall, snow-melt, temperature, ground-surface conditions and runoff.

A research project which is believed to be of very real significance is one that is now being conducted cooperatively with the Corps of Engineers to estimate spillway and waterway capacities. The procedure is to make a detailed study of major storms that have resulted in excessive precipitation and floods, transpose these storms within reasonable limits to other locations with respect to nearby river basins, take other factors such as topography, snow cover and a different temperature distribution into consideration, and endeavor to determine what is the maximum run-off that is ever likely to occur. This is a direct application of the work that is being done in air mass analysis, the

isentropic chart, previously referred to, playing a prominent part. It is planned to extend this study to all of the principal river basins in the country.

Hurricane Warning Service.

Another good example of present trends is the hurricane warning service which was materially strengthened three years ago. The main features are: (1) a 24-hour teletype service connecting points along the Gulf of Mexico and South Atlantic coasts, from Brownsville, Tex., through Key West to Jacksonville, Fla., thus providing for frequent exchange of reports and prompt transmission of forecasts, (2) an increase from two to four reports daily from ships in the Gulf of Mexico, West Indies and Caribbean waters; (3) close cooperation with the Coast Guard; and (4) the assignment of specialists trained in hurricane forecasting to New Orleans, Jacksonville and San Juan.

Along with the development of this service there has been organized, cooperatively with the Massachusetts Institute of Technology, a research project which consists in sending up recording apparatus, attached to balloons, during the passage of hurricanes, preferably as near their centers as possible. Only a few records thus far have been secured, but they show some interesting features regarding atmospheric structure in the upper portions of these storms. This investigation is being continued in the hope, not that hurricanes will occur but that, if they do occur, we shall obtain information that will increase our knowledge of their characteristics and thus enable us to forecast their formation and movements more accurately.

Research

Time does not permit consideration of many other examples of the present tendency to specialization of service. In all of them, as well as in those that we have discussed, research is playing an increasingly important role. A broad comprehensive research program is in fact fundamental to any future progress. The Weather Bureau is limited as to funds for the development of such a program, but fortunately the Bankhead-Jones Act for research in the Department of Agriculture makes possible a definite beginning along this line. Only brief mention can be made of a few of the more important of these projects. One of them is an investigation of the conditions which give rise to the building up of huge domes of polar air in Alaska, these later moving southward and developing into the cold waves that invade and spread over large sections of this country. Upper air soundings with airplanes and radiometeorographs, together with measurements of outgoing radiation, have been made at Fairbanks, Alaska, Fort Smith, Canada, and at points along our northern border. Already some significant conclusions have been reached, although it is too early to announce any definite results.

Attention is not being limited to winter conditions, however. Equally important, in some respects more important, because of their relation to agriculture, are studies now in progress to apply air mass analysis methods, and particularly the isentropic chart, to the forecasting of thunderstorms and precipitation generally during the summer season. The number and frequency of upper air soundings are not yet adequate for this investigation, but the results thus far nevertheless give a substantial basis for optimism that forecasting of summer rainfall, including thunderstorms, will be materially improved and that the period of the

forecasts can be extended to something like five days, possibly longer.

An investigation of considerable promise has to do with solar variations as they may affect the atmospheric circulation, and special attention is now being given to the question of atmospheric ozone as a possible link between solar activity and changes in the circulation of the atmosphere. Measurements thus far made show that ozone is greatest in amount a short distance to the rear of low pressure centers and least in the corresponding part of high pressure areas. It would seem then to be a valid assumption that the variations in the amount of ozone are related not to the barometric pressure itself but rather to the sources of different air masses, the ozone being most abundant in polar and least in tropical air. There is thus the possibility of utilizing the measurements of ozone and its variations in forecasting the development and movement of the different types of weather that are associated with fronts, anticyclones, cyclones, etc.

Many other problems are being attacked in a very definite way, such as the conditions that produce ice formation on aircraft and widespread sleet and ice storms that cause so much damage to power lines. The hazard of lightning to aircraft is now receiving special attention. Nearly all of these investigations are being conducted cooperatively, in part with other Government agencies, in part with educational institutions and in part with interested individuals. Meteorological services of other countries are likewise active. It is in fact one of the hopeful signs of the times that research is assuming its proper place in the development of modern meteorology.

Conclusion

Attempt has been made to outline briefly some of the main features of the present program of reorganization of the Weather Bureau designed to bring about improvements in the service, including particularly forecasting. It will be noted that much of this relates to the future. Nevertheless, very real progress has been made in some lines already. The point of real significance is that we have definitely broken away from an ultra-conservative attitude, from dependence on old established methods, and are developing the service in line with modern scientific thought and procedure. Encouraging results already are being realized; others are bound to come as the program is continued and extended.

Acknowledgment

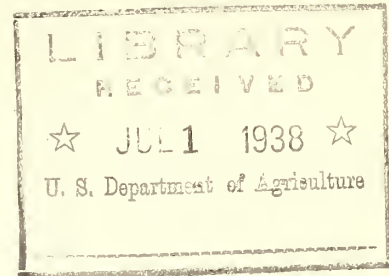
The author is indebted to Dr. Horace R. Byers of the Weather Bureau for helpful suggestions in the preparation of the sections of this paper on "Physical Basis of Forecasting" and "Research."

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THE RADIOMETEOROGRAPH.

By

Willis Ray Gregg,
Chief, U. S. Weather Bureau.



(Address delivered at meeting of the Institute of the Aeronautical Sciences, Inc., Ottawa, Ontario, June 29, 1938.)

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Introduction

During recent years many meteorological services have given increasing attention to the development of the radiometeorograph, or, as it is frequently called, the "radio-sonde". That the potentialities of this method of upper air exploration are fully recognized is evident from action taken by the International Meteorological Committee at its meeting in Salzburg in September 1937. The resolution which was unanimously adopted at that meeting reads as follows:

"The development of the radio-sonde has placed at the service of synoptic meteorology a new and powerful instrument for the exploration of the upper atmosphere in all conditions of weather.

"Full use of the observations which the instrument provides requires the cooperation of all meteorological services to establish a network of such stations. Only by the provision of a network of stations can the construction of the necessary upper air and particularly stratospheric charts be prepared.

"The Committee considers that a network of about 50 stations is necessary for Europe and a corresponding density is desirable for other parts of the temperate zones. A network of stations is equally necessary in the Tropics and polar regions.

"The Committee recognizes that the maintenance of these stations and the provision of the personnel required to operate them will involve considerable expense; but it is convinced that further substantial advance in forecasting, and the solution of the problems arising from the extension of flying to great distances and heights, depends on the establishment of an organized system of radio-sonde observations."

This formal resolution was followed by a suggested apportionment of stations among European countries and other regions of the world. Since 50 are recommended for Europe and "a corresponding density for other parts of the temperate zones", the number for North America would amount to something like 125. It was encouraging to note that the representatives of all countries accepted their quotas with enthusiasm and

indicated a determination to make every possible effort to carry out their part of the program.

This attitude on the part of the international delegates is illustrative of the widespread interest in this new field, - an interest which manifests itself in an almost feverish activity in many countries, both by meteorologists and by radio engineers. Several designs have been developed and many articles have been written and published. A highly encouraging feature connected with all this activity is the arrangement that has been made by the International Aerological Commission for exchanges of reports of progress, which include also detailed descriptions of the apparatus that each is developing. In other words, the goal is not individual glory, but the most efficient product possible. Thus, through this exchange of reports, the best features that are being developed by those now working on the problem will ultimately find a place in a few, probably not more than two or three, standard types. It is the purpose of this paper (1) to give a brief review of the present state of this development and (2) to speculate a little regarding the significance that the adoption and use of this method of aerological exploration will have in meteorological theory and practice.

Briefly Historical.

The idea of utilizing radio in securing upper air data was first suggested nearly a quarter of a century ago. Soon several investigators were working on the problem and some preliminary and partially successful tests were made from 1918 to 1927 in France, Germany and the United States. The first really successful results, however, were obtained at Slutsk, near Leningrad, U.S.S.R., in 1930, under the direction of P. A. Moltchanov. Since then progress has been rapid, a large number of reasonably satisfactory soundings having been made during the International Polar Year, 1932-33. At the present time daily records are being obtained at several points in some of the European countries and, during the fiscal year now closing, at two stations in the United States, Boston, Mass., and Burbank, Calif., with occasional soundings at Fairbanks, Alaska. Within a few days, viz, on July 1st, regular observations will be made daily at 6 places in this country, and we are confident that a year hence this number will be materially increased.

Basic Features of Designs Now in Use or in Course of Development.

The radiometeorograph consists essentially of a radio transmitter which is actuated by a barometer, a thermometer and a hygrometer, all of extremely light weight but high precision. Four principles of operation have been employed. The most widely used is the Olland system of telemetering (a simple form of television) in which an attempt is made to telemeter the position of the index of the meteorological element relative to a time scale. The next in order of general use is one in which the meteorological elements vary the capacities of the radio frequency oscillator thereby varying the carrier frequency. Another principle of operation is to key the carrier by means of the meteorological elements,

thus causing a sequence of coded signals to be transmitted. Finally, there has been employed an audio oscillator whereby the carrier frequency is modulated and produces variations in modulation by changes in resistance that are varied by the meteorological elements.

In general, high frequencies are employed, varying from about 60 to more than 150 megacycles. In some of the earlier types the signals were received aurally, but now as a rule recording devices are attached to the receivers, and complete records are made on tape or on a sheet of paper.

In instruments which are based on the Olland principle the pressure, temperature and relative humidity elements are so mounted on a frame that the contact points on their index arms move along the circumference of a circle. A clockwork rotates a metal arm which makes an electrical contact with the index of the elements as it sweeps past them. It follows that if the elements move, the time interval between their contact and a fixed reference contact will change. It is this variation of the time interval between contacts which becomes a measure of the numerical values of the elements. It is evident that if the clockwork does not rotate the contactor uniformly, the time interval between contacts will show variations which would not be due to changes in the position of the elements. In other words, the apparent readings will be in error depending upon the irregularity of the clock. This feature is now receiving close attention and further developments are expected.

Types Developed in United States.

In the United States four different designs of the Olland instrument have been developed. These differ slightly in construction, partly in the meteorological elements, but chiefly in the assembly, particularly in the method of driving the contacting mechanism.

One of these has been used with fair success at Fairbanks, Alaska. It makes use of the Archimedes spiral contacting device, developed by the Weather Bureau, but modified so that one Olland cycle covers the displacement of each of the meteorological elements. While the clockwork is rugged, and operates satisfactorily at low temperatures, its rate varies somewhat, causing the duration of the cycle to vary and consequently resulting in a loss of accuracy. This has been the only serious difficulty with the instrument but it is important in that, not only is accuracy diminished, but evaluation of the records becomes very tedious. Unless there is synchronization of the radiometeorograph clock and the recorder, as could be obtained by a satisfactory clock motor, the Olland system of radiometeorography loses its chief advantage over other types of radiometeorographs. The latest instruments have been built with an improved clock motor, so that timing variations have been reduced somewhat, resulting in improved records.

At Boston the Harvard-Blue Hill type of radiometeorograph has been used. In this instrument the clock is an ordinary pocket watch, whose beats have been increased to 600 per minute in order to increase accuracy.

Inasmuch as there is always some uncertainty in time measurement, due to clock irregularity (the contacting mechanism is moved in steps with each tick of the clock) as well as delayed electrical contacts, an attempt has been made to increase accuracy by spreading the motion of the meteorological elements over two or more Olland cycles. This is done by a helix on a rotating cylinder making the contacts. The Olland cycle will then be over one turn of the helix while the elements move over two or more turns. Unfortunately, the clock in this instrument has not been operating satisfactorily. Although it has shown the best synchronization, it tends to stop at temperatures below -10°C . Very few clocks have operated at temperatures below -40°C . Most of the low ascents made at Boston have been doubtless due to failure of the clock. Recently the balsa wood box, within which the clock is mounted, was covered with several thicknesses of thermal insulation which resulted in a considerable increase in the average altitude. From last reports, the clocks are now taken apart, and after reassembly without a trace of oil, will run successfully at temperatures below -60°C .

The Galcit type is used at Burbank. It is very similar in operation to the Weather Bureau type. One Olland cycle covers all the meteorological elements. A very rugged clock is used whose escapement has been speeded up to about 2,000 beats per minute, in order to increase precision. Precise readings are further facilitated by having more than one reference contact, so that any variation of time within the cycle can be noted. The latest development of this instrument has been a heavier mounting for the meteorological elements, and some improvement in the clock escapement.

One of the first of the Olland type of instrument to be developed in this country was designed by Curtiss and Astin of the National Bureau of Standards. This instrument has an electric motor, instead of a clock, for operating the Olland cycle. Developments on this instrument have been chiefly on the electric motor which has now been made to operate at constant speed; also a more powerful drive than a clock without any increase in weight. A set of these radiometeorographs is now under construction, and if tests with them prove successful it is quite likely that all Olland type meteorographs will change to the motor drive, for it will be possible to obtain the complete cycle in a few seconds instead of 30 seconds as is done now. In this way there will be a practically continuous record of the ascent instead of an intermittent one.

A radiometeorograph, differing markedly from any of the foregoing and employing an audio oscillator, has been developed by Diamond, Hinman and Dunmore, also of the National Bureau of Standards. This instrument has no clock or other rotating mechanism, utilizing instead the decrease in atmospheric pressure as the balloon rises for moving a small switch arm over a series of equally spaced contacts that are separated by insulating strips. The contacts are so spaced that, for a decrease in air pressure equivalent to a few hundred feet, the switch arm moves from one contact to the next, causing the radio transmitter to send signals having predetermined audio notes that identify these contacts.

Contacts intermediate to those identifying pressure are wired to a resistor controlled by a hair hygrometer. The switch arm passing over these contacts connects this variable resistor into the transmitter circuit so as to send signals having an audio note proportional to the value of the resistor.

When the switch arm passes over the insulating strips lying between the contacts, the frequency of the audio note is determined by the electrical resistance of a small glass tube filled with sulphuric acid. The resistance of this column of acid changes markedly with temperature so that the transmitted note may be interpreted to evaluate the air temperatures at all heights reached.

Receiving and recording equipment at the ground station is employed to plot the data on a chart which moves under a pen controlled by the signals. This pen sets itself according to the pitch of the audio note that is being received. The final record gives a complete picture of the variations of temperature and humidity as functions of height above the earth's surface.

European Types.

Of the radiometeorographs that are used in Europe one of the best known is that developed by Moltchanov of the Soviet Meteorological Service. This instrument is ingenious, though complicated and somewhat difficult to construct. The arms of the meteorological elements play over a set of contacts resembling the teeth of a comb, each tooth being connected to one of seven contact switches. A fan which rotates as the balloon ascends, turns a cam on each of the contact switches, completing an electric circuit through one cam, switch, and tooth with which a pen arm is in contact. Since the cam is turning, a characteristic signal is given out and is received as a combination of dots and dashes. As there are only seven switches, it is necessary to use the sequence over and over again, and interpret the values of the elements by their signal and its sequences and time. The record depends both on uninterrupted of signal, and on an absence of radio interference that would change the signals.

Another type which has been successfully used, and is very low in cost besides, is the Väisälä Radiometeorograph used in Finland. It uses the variation of the carrier frequency as a means of transmitting signals. The meteorological elements are so built that their displacement varies the capacity of a condenser, and this variation in turn changes the frequency of the radio signal. The slip stream from the ascending balloon turns a fan which furnishes power to rotate a five-point commutator switch so that the radio circuit is connected first to one element, then to another. Three of the contacts lead to the three meteorological elements; the other two, to fixed condensers. These normally give signals at a constant frequency and serve as references from which the numerical values are determined.

A third type, developed in Germany by Duckert, depends for its operation on a combination of keying and variation of radio frequency. The

instrument transmits a continuous signal whose frequency is a measure of temperature. The pressure element is so constructed that at certain predetermined pressures the signal is interrupted, while the humidity element controls the duration of this interruption. Inasmuch as a change of radio frequency is a measure of temperature, it is essential that the transmitter itself should not drift in frequency. For this reason, it is housed within a vacuum tube, and thus is protected from temperature and humidity changes which are the chief causes of frequency drift.

The French have developed an instrument known as the Bureau Type which operates essentially on the Olland principle. However, instead of using time intervals as a measure of deflection of the meteorological elements, a number of impulses are used, and in this way errors in measurement due to clock irregularities are eliminated. A clockwork drives a rotating cylinder on which the index arms of the meteorological elements play. For each revolution of this cylinder, there is a fixed number (about 1,200) of impulses sent out. As the contactor on the cylinder comes under the index arm of one of the elements, the impulses are interrupted, and the count of impulses between interruptions is thus a measure of the numerical value of the element. An oscillograph on the ground records the impulses and interruptions and from these the evaluation is made.

Experience with Different Types in the United States.

All of the instruments above briefly described have certain advantages and disadvantages. Generally speaking, our experience is that those designed in the United States are better adapted to current or routine use, since the data received from them are in such a form that evaluations can be more quickly made. When soundings are to be used in synoptic work, it is highly important that the salient points of the record be worked out promptly.

In addition to this matter of speed two of the European designs, the Väisälä and the Duckert, are of the variable frequency type, which has the disadvantage of so broad a radio frequency channel as to cause interference in other channels which would of course automatically rule them out so far as the United States is concerned.

During the fiscal year closing June 30, 1938, the Weather Bureau has used three different forms based on the Olland system and the results have been reasonably satisfactory. These instruments have the advantages of moderate cost and simplicity of calibration. On the other hand, they require a reliable clock or other rotating device having the qualities of uniform speed and freedom from stoppage at low temperatures. Much further development along these lines is necessary. If absolute synchronization of the radiotelemeter motor with that driving the recorder mechanism is brought about, the Olland type of instrument will certainly be a strong contender in the final choice for regular use.

The National Bureau of Standards' design which employs an audio oscillator to modulate the carrier frequency gets away from the handicap of erratic clocks or motors, but is thus far somewhat more costly to construct.

Tests during the past year have resulted in consistent development and improvement, and it is the plan of the Weather Bureau to use this type at six points daily during the fiscal year beginning July 1, 1938. As previously stated, the temperature element is a glass capillary tube filled with an electrolyte, whose electrical resistance changes markedly with temperature, and whose time response is satisfactory for meteorological use.

Experimentation is now in progress on the development of a resistance hygrometer, which consists of a thin-walled glass tube about an inch in diameter round which are wrapped two parallel wires, the glass tube having previously been dipped in a 1 to 5 percent hygroscopic solution. Changes in humidity produce corresponding changes in resistance between the wires, these in turn altering the audio frequency. Difficulties are being experienced in the design of this element but there is good basis for hope of success. If this hope is realized, one of the major weaknesses in aerological exploration, namely, the impossibility of measuring rapid changes in humidity at low temperatures with the hair hygrometer, will be eliminated, and this will mark a very definite forward step in meteorological service.

Aside from the continuing experimental and development work already outlined, attention is now being given to the utilization of radio direction finding devices in conjunction with radiotelemeters for the purpose of measuring wind direction and velocity aloft in all kinds of weather. Very little progress has been made thus far in developing this part of radiometeorography and it is impossible to say which type of radiotelemeter will be most suitable for the purpose, or whether a special form of radio-transmitter, without the telemetering mechanism, will be used. At present the problem is being attacked separately by the National Bureau of Standards and the California Institute of Technology with each of which the Weather Bureau is cooperating. The problem will be solved - there is no question as to that, though considerable time may be necessary - and when it is solved another great handicap in the study of conditions aloft will have been removed, namely, the absence of data on air movements at great heights during periods of unfavorable weather.

Significance of the Radiometeorograph in Meteorological Service of the Future.

In view of all the activity and enthusiasm regarding the potentialities of this new method of aerological exploration we may well ask ourselves what the benefits really are going to be. And perhaps the best way to do that is to consider what is being done with the much less complete upper air data that are now secured by means of pilot balloons and airplanes which, though subject to serious limitations, are nevertheless enabling us to substitute a three-dimensional for the former two-dimensional visualization and study of the atmosphere. Until upper air data were available it was necessary to develop forecasting largely on the basis of correlating certain types of pressure distribution and pressure change with subsequent weather. Much progress was made in the use of this method, but, being empirical, a "dead line" of dependability was soon reached beyond which further improvement was not attainable.

With upper air data available, from kites, balloons and more recently from airplanes, it was soon found that it is not the cyclones and anticyclones as such that are important in determining weather, but rather the interactions between the various air masses that go to make up those systems of high and low barometric pressure. These air masses from different source regions, polar, equatorial, continental and marine, have distinct characteristics of temperature, humidity and movement, and they tend to maintain their individual identities over comparatively long periods of time, with the result that at their surfaces of contact they form more or less marked discontinuities or "fronts". It is along these frontal surfaces that the processes involved in weather phenomena are most active, and the study of them, now generally referred to as "air mass analysis", already has proved itself a powerful aid in developing forecasting along sound physical lines.

The introduction of a new technique, especially when it involves the use of data of a type not previously available, requires careful study to determine the most effective means of presenting those data for rapid and thorough analysis. The "raw" observational material is useful in showing the current state of the individual meteorological elements, but offers little aid in an understanding of the energy transformations that are taking place. For this latter purpose various so-called "energy diagrams" have been devised which bring out clearly the more prominent characteristics of the air masses that are present and give us a picture of the structure of the atmosphere as regards its temperature, humidity and other conditions.

The adiabatic chart is the fundamental diagram for plotting the data from individual ascents. The sounding is plotted with temperature as abscissa, and pressure on a logarithmic or exponential scale as ordinate which is approximately equivalent to a linear altitude scale. On the diagram, we may readily locate the various temperature inversions (atmospheric strata in which the temperature increases instead of decreases with height) which are significant as marking the tops of turbulent and convectively-stirred regions and which also coincide with the tops of haze, smoke, and cloud layers. Furthermore, these temperature inversions, especially if accompanied by inversions in the vertical distribution of moisture, may signify the presence of frontal surfaces. Adaptations of the adiabatic chart have been devised, from which the energy realizable for vertical convection can be determined, - one of the few precise physical computations that can readily be applied to forecasting and is of great value in forecasting local showers and thunderstorms. The procedure consists in following the changes that would occur were an isolated element of surface air forced to move upward along an adiabatic line, and comparing its temperature, and therefore its density, at each level with that of the surrounding atmosphere through which the element is forced to rise; the conditions in the surrounding medium are given by the data of the airplane observation. If the isolated rising air finds itself in an environment that has a lower temperature, then it will not be in stable equilibrium and will be accelerated upward, thus being capable of producing the strong ascending currents necessary for the formation of thunderstorms. In its ascent the air, after reaching the condensation level of its water vapor, cools at the so-called saturation - or pseudoadiabatic rate, which is less

rapid than the adiabatic cooling rate before condensation because of the gradual release of the latent heat of vaporization in the cloud. A convective-energy diagram called an "emagram", based on the adiabatic chart, with temperature as abscissa and pressure as ordinate, is highly useful, since it shows, by its so-called "positive area", the amount of energy that is available for convection.

Another valuable form in which the upper air conditions can be quickly visualized is by means of the so-called "vertical section" which shows temperatures, relative and specific humidities, winds, clouds, etc., as ordinates and a geographic section of the country, west to east, north to south, or any other direction, as abscissae. Necessarily the vertical scale is greatly exaggerated. Several such vertical sections are required to show the conditions for the entire country. We have not as yet been able to devise a method that would combine all into one chart, nor is it likely that we ever shall be. However, a study of these vertical sections, together with the surface weather map, enables one to form a fairly comprehensive picture of the distribution, both horizontal and vertical, of the various air masses and of the surfaces of discontinuity separating them.

One of the most recent and most promising advances in charting the upper air is the development of the so-called isentropic charts. This method is based on the fact that in the free atmosphere, most movements are along adiabatic or isentropic surfaces, i.e., surfaces of constant potential temperature; potential temperature is defined as the temperature attained in an adiabatic reduction of pressure to 1000 millibars (one million dynes per sq. cm.). Instead of drawing charts of the air currents on level surfaces, or surfaces of constant height, we chart the circulation along the isentropic surfaces, which normally are sloping surfaces, and thus we follow the currents along the surfaces on which they actually move. The paths of the air currents can be traced by following the course of "tongues" of water vapor maxima that appear on the charts. These moist tongues, especially where they are carried in currents moving rapidly upward along the isentropic slope, are correlated with areas of precipitation and cloudiness. In forecasting the behavior of these tongues, one can arrive at a very good idea of the future course or development of precipitation areas. A study of these charts has shown that the atmospheric circulation tends to break up into much smaller eddies than was previously supposed to be the case. New theories of the general circulation of the atmosphere are being developed from these findings.

A definitely physical approach to the problems of forecasting has thus been made possible through the data, incomplete but highly valuable, that have been made available by kites, balloons and airplanes. It is certain that, with regular soundings well up into the stratosphere, under all conditions of weather, useful relations will be established between temperature and elevation of the stratosphere and weather conditions at the earth's surface. Even from a few isolated observations we have learned that many centers of low pressure owe their development or continuance to peculiar conditions in the stratosphere and by watching these developments in detail there is abundant reason to believe that they can be used effectively in weather forecasting.

The regular use of the radiometeorograph will in fact mark the beginning of a new epoch in meteorological service. Attached to a balloon it will ascend to heights of 10 to 20 miles, securing data in all conditions of weather, thus overcoming a serious handicap to which all other methods are subject. And finally it will give us those data immediately while the balloon is ascending instead of our having to wait two or three or more hours after the sounding is completed.

Nor will the benefits be limited to our knowledge of the upper air. These instruments, or apparatus based on the same principle, can be placed on small islands, - for example, in the West Indies and Caribbean Sea to give data of inestimable value during the hurricane season. The same use can be made of the apparatus on islands in regions which are subject to destruction by typhoons.

It is generally recognized that great benefit will result from more detailed information regarding conditions in the polar regions. Such information will be secured through the organization of a network of stations in regions where man does not live. It will be perfectly feasible to install the equipment which will transmit the data as frequently as desired, and which can be kept functioning through only very rare inspection visits by means of an airplane.

Again, much thought is being given at present by practically all meteorological services to the desirability of taking up mountain observatory work more actively than ever before. The great difficulty is that establishing observatories on very high summits involves many problems and large cost. The radiometeorograph will solve this problem also, and at comparatively small expense.

The possibilities for the use of the principle of the radiometeorograph or the "robot observer" are, in fact, almost endless and abundantly justify all the feverish activity that is now in evidence in many countries in bringing the equipment to a point where it can be used in regular service.

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